Vol. V.] *Issued Quarterly. Single Numbers,* 8/6 *net.* [No. 20.

Subscription 31/6 *net, per annum, post free. Volumes commence in JULY. Title and Index supplied with the APRIL number. Cases for Binding,* 3/- *net; or the Volume bound in Case on receipt of the four numbers, for* 5/- *net, post free.*

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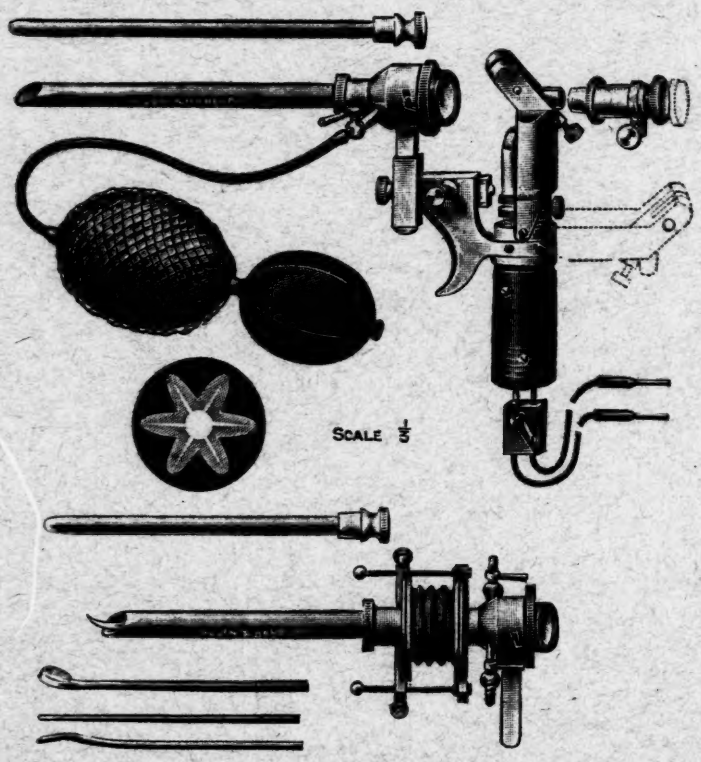

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JOHN ARDERNE.

1307–1380 (?).

JOHN ARDERNE is the first English surgeon of whom we have any detailed knowledge at present. He lived so early in the history of English surgery that he shows traces of the barren Saxon period when charms and wort cunning were prevalent, intermingled with the more fertile scientific methods derived from the schools of Salernum and Montpellier—methods which rendered possible the work of Lanfrank in Italy, of de Mondeville in Paris, and of Gui de Chauliac at Avignon. Arderne lived through the fourteenth century, and was essentially a general surgeon practising amongst all classes, first in the wars, then at Newark, and last of all, as an old man, in London. He was held in high esteem by his contemporaries, who admitted him to the Guild of Surgeons in London; and his teaching was so greatly appreciated by his successors, that numerous manuscripts of his writings still exist, both in Latin and in English translations.

Born in 1307, he was certainly writing as late as 1376, and perhaps for some years afterwards. He thus lived through the reign of Edward III, and being attached to John of Gaunt, he knew personally many of the heroes of the Hundred Years' War, men whose names are household words, for they live for ever in the pages of Jean le Bel and of Froissart. At a time when chivalry reached its highest development, Arderne lived with the most chivalrous. He seems to have visited Flanders, Algeçiras, and Guienne, and gives a few facts about his experiences in each place. He settled at Newark on Trent in 1349, perhaps because the ravages of the Black Death caused a temporary cessation of hostilities in France and compelled the military surgeons to seek a more peaceful livelihood. He practised at Newark until 1370, when he moved to London and was admitted into the Fellowship of Surgeons, a small guild distinct from the Fellowship of Barbers. The existing writings of Arderne are dated after his settlement in London, and are a series of tracts, or monographs as they would now be called, dealing with subjects of medical and surgical interest. It is clear from these articles that fistula resulting from spear and arrow wounds interested him, but he had no knowledge of gunshot injuries. The knights and gentlemen wore heavy armour, spent many hours in the saddle in all weathers, and were much constipated. They often suffered therefore from ischiorectal abscess followed by fistula in ano. Arderne boldly invented and used the operation of incision for fistula, and was so far in advance of his time that it fell into disuse after his death, and was not revived for nearly five hundred years. His patients ate and drank to excess, so he wrote a treatise on gout, and another on the diet of those with disease of the kidney. Scabies then, as now, was the scourge of camps, and he gives many directions for its cure. Gonorrhœa, or 'brenning,' was frequent, but of syphilis there is no hint. Hysteria or 'strangling of the matrice' he knew well and treated drastically.

He had learnt the great secrets of success in surgery: fearlessness as regards bleeding; cleanliness; infrequent dressing of wounds. These points are easy for us to grasp, but were most difficult for mediæval surgeons, who had no means of arresting hæmorrhage, and who had been taught for ages that wounds could only heal properly if they suppurated and so discharged their venom. In addition to his skill as a surgeon, Arderne was endowed with a sound common sense which enabled him to recognize the limits of his art, and when a case was incurable he did not hesitate to express his opinion, even if he lost his patient by so doing. Arderne recognizes several clearly defined grades of medical practitioner. There was the 'lady,' who gave simple advice and treatment; the apothecary, who sold drugs and plasters; the leech, sometimes skilful, more often foolish, who treated the patient before he brought him to the master surgeon—such an one as John Arderne himself; lastly, the physician, with whom the master surgeon often consulted, and seemingly on more equal terms than was the case several generations later.

Arderne lays down two cardinal rules for wound treatment. The spelling is modernized, the sentiments are his own: "To a leech be this a rule, that corrosive powder be never removed in a wound or an ulcer until it comes out of its own accord. Also there is another rule in which I have seen err in my time almost all men not practical but fools: that is to say, of the frequent dressing of wounds or ulcers. Such dressing speedeth not the cure but preventeth it. And when such idiots be openly known and not reproved, they vex themselves and their patients by their ignorance. He is a leech in name but not in discretion who uncunningly dresses a sore twice in a day. Galen sayeth the tree plant that is often changed shall not recover, and Hippocrates sayeth the wound becometh less healthy which is often re-dressed. Wounds therefore show such men to be idiots who are diligent and busy when it would profit more to both parties to rest than to labour in vain. They say the weather is hot, or the wound runneth or stinketh strongly, and therefore it is better to dress it often. This is untrue and followeth not, for though they say that the wound runneth strongly, and that the oftener it is dressed the better—that is to say twice or thrice in a day—it is not so, for such treatment preventeth the coming out of the matter, and the wound or botch is made worse, as is shown by experience. Let a leech be content with one dressing a day, and when he seeth a wound or an ulcer well cast out its discharge and the swelling for to vanish away and the aching for to cease and the member to come again to its first habit and colour, health is at the door if the patient be well governed, i.e., if he sleep well o' nights. Often times in many cases I was not wont to re-dress a wound but from the third day unto the third day, and I sped well and cured many difficult cases which had been forsaken by other men."

Arderne's operation for fistula is a modification of the method recommended, but apparently not used, by Albucasis (d. 1013), who taught that complete fistula was incurable, and that all operations and application of ointments were but labour in vain. Arderne recommended that a clean incision should be made through the fistula instead of fretting it through with a ligature tied tightly, as was done by all his predecessors, contemporaries, and successors. For this purpose he placed the patient in the

JOHN ARDERNE OPERATING FOR FISTULA IN ANO

lithotomy position, and passed a probe through the fistula until it was felt in the rectum. The eye of the probe was threaded with a ligature of four strands, which was drawn along the fistula as the probe was pulled out of the rectum, until one end hung out of the anus, the other from the external opening of the fistula. The two ends were knotted together, and were tightened by means of a peg fixed into the widest part of a gorget, in the same way that a violin peg tightens the string passing round it. The ligature was used partly to control the bleeding and partly to maintain a correct line whilst the fistula was divided. The gorget was now pushed well into the fistula, and a grooved director with a curved end was passed along it until the end projected into the rectum. A shield with a depression in its centre was then passed through the anus until the grooved director engaged in the depressed notch. The shield prevented the surgeon cutting down on his own finger, and at the same time protected the opposite wall of the rectum in case the patient struggled or made any sudden movement at the moment the fistula was divided. A scalpel was passed along the groove in the director, and the fistula was cleanly divided along its whole length by drawing the knife, the director, and the shield out of the rectum with a single movement, the ligature coming away at the same time. "Then it is to labour to stanch the blood. First put a sponge, wet in a little warm water and well wrung out, into the place of the cutting, and hold it there for it to receive the blood, and let it abide there a good while. When thou trowest the sponge to be full of blood, remove it, and if there be need, put again another sponge or the same ordained in the foresaid manner. And when thou hast done thus, have the patient raised warily, and make him sit hard in a convenient place upon the aforesaid sponge, and doubt not but that it shall be well stanched. Afterwards, when you deem it due time, be the patient put in a proper place and the sponge removed, and whether the blood be stanched or not, sprinkle it with a powder and apply clean and small stupes or well-teased cotton with linen clouts put on above. Let him be girded with a linen girdle, and afterward have a list of woollen cloth bound behind to the girdle, and let it descend atwixt his buttocks upon the clouts covering the perineum and be it fastened to the girdle upon the belly" [a T-bandage]. The cure was aided by daily enemata of oil injected through a wooden clyster pipe.

"For the cure of fistula in ano, when it is curable, ask of a worthi man and great an hundred marks or forty pound,* with robes and fees of a hundred shillings a year so long as he lives. Of lesser men forty pounds or forty marks ask he without fees. And take he not less than an hundred shillings, for never in all my life took I less than an hundred shillings for cure of that sickness.

"And if the patients or their friends or servants ask by how much time he hopeth to heal it, evermore let the leech state the double that he expecteth, that is if the leech hope to heal the patient in twenty weeks—that is the common course of curing—add he so many over, for it is better that the time

* Forty pounds in 1367 purchased an annual rent charge of sixty shillings. The value of money was probably ten to fifteen times greater than it is at the present time.

be lengthened than the cure. For prolongation of the cure giveth cause of despairing to the patients when trust in the leech is most hope of recovery. And if the patient consider or wonder or ask why that he put him so long a time of curing when he healed him in half the time, answer he that it was because the patient was strong-hearted and suffered well sharp things, and that he was of good complexion and had able flesh to heal, and feign he other causes pleasing to the patient, for patients of such words are proud and delighted."

Arderne records his cases briefly, and yet so clearly that there is no difficulty in making a diagnosis. The following, for instance, is a case of traumatic tetanus with secondary hæmorrhage: "A gardener while that he wrought in the vines cut his own hand with an hook upon a Friday after the feast of St. Thomas of Canterbury in the summer, so that the thumb was altogether departed from the hand save only in the juncture that was joined to the hand, and he might bend backward the thumb to his arm, and there streamed out thereof much blood. And so touching the cure; the thumb was first reduced into its first order and sewed, and the blood was restrained with the red powder of Lanfrank and with the hairs of a hare, and it was not removed until the third day; and on the third day when it was removed there appeared no blood. Then was there put thereto those medicines that engender blood, every day once re-dressing the wound, and so it began to purge itself and to gather matter. And in the fourth night after, the blood brake out about midnight to the weight of two pounds. And when the blood was restrained the wound was dressed again from day to day as it was at first. Also in the eleventh night about the foresaid hour the blood brake out again in more quantity than it did aforetime, nevertheless the blood was stanched, and by the morn the patient was so taken with the cramp in the cheeks and in the arm that he might receive no meat into his mouth, neither could he open the mouth, and so vexing the patient. In the fifteenth day the blood brake out again, and in the eighteenth day the blood brake out again out of all measure, and alway the cramp endured forth, and in the twentieth day he died."

Arderne, like most of his contemporaries, details the qualities to be found in a successful surgeon, and drives his meaning home in a series of apophthegms. Amongst other things, let the chirurgeon "be found evermore sober, for drunkenness destroyeth all virtue and bringeth it to nought; as sayeth the wise man, 'Ebrietas frangit quicquid sapientia tangit,' 'Drunkenness breaketh what so wisdom toucheth.' Scorn he no man, for of that it is said, 'Deridens alios non inderisus abibit,' 'He that scorneth other men shall not go away unscorned.' If there be made speech to him of any leech, neither set he him at nought, nor praise him too much or commend him, but thus may he courteously answer: 'I have not real knowledge of him, but I learned not nor heard of him but what is good and honest.' And of this shall honour and thankings of each party increase and multiply to him; after this, 'Honour is in the honorant and not in the honoured.' In as much as he may, grieve he no servant, but get he their love and their good will. Abstain he him from harlotry as well in words as in deeds in every place, for if he use harlotry in privy places, sometime in open place

there may fall to him unworship of evil usage, after that it is said 'Pede super colles, pedes ubi pedere nolles.' When sick men cometh to the leech to ask help or counsel of him, make he covenant for his travail [agree upon the fee] and take it beforehand. But let him give no certain answer in any case unless he first see the sickness and the manner of it. Have a leech also clean hands and well shapen nails and cleansed from all blackness and filth. Hear he many things but speak he but few. For a wise man sayeth, 'It beseems more to use the ears than the tongue.' And in another place, 'If thou hadst been still thou hadst been holden for a philosopher.' Also it speedeth that a leech can talk of good tales and of honest that may make the patients laugh whilst they make or induce a light heart in ye sick man. Discover never the leech unwarily the counsels of his patients—as well of men as of women—nor set not one to another at nought although he have cause to do so, for if a man see thou hele [conceal] well another man's counsel he will trust better in thee."

Arderne appears to be the only contemporary authority for the story of the means by which Edward the Black Prince obtained the ostrich feather which has since become the cognizance of the heir-apparent to the English throne. The passage runs as follows: "We can not cure rhagades unless the remedy can be put through the anus either as a clyster or by means of a suppository, since remedies applied outside are either useless or do very little good. We ought, therefore, to wash with stimulating applications until the wound is clean, and afterwards with applications which both heal and dry, as has been already pointed out in the chapter on Internal Piles, to wit, where Nastar is painted—and Nastar is a kind of clyster or enema known as a clyster-pipe. The feather of the Prince of Wales is also shown there, viz., on the preceding page. And note that Edward, the eldest son of Edward king of England, bore a similar feather above his crest, and he obtained the feather from the king of Bohemia, whom he killed at Cressy in France. And he took the feather, which is called an 'ostrich feather,' which that most noble Lord King had used hitherto to bear above his crest. And in that year when our lord the strenuous and warlike Prince departed to God, I wrote this little book of mine with my own hand, viz., in the year one thousand three hundred and seventy-six. And our Lord Edward the Prince died on the sixth of June on Trinity Sunday at Westminster during the great Parliament, May God assoil him for he was the very flower of chivalry without peer in the world."

There is a curious sidelight on Arderne's experience of the profligacy of the times, when he directs, in making the styptic powder called pulvis sanguis veneris, that there should be taken "the blood of a maiden virgin, or of a damsel about 19 or 20 years which was never with child though she be corrupt, for now in this time virgins cometh full seldom to 20 years."

The illustration, showing a Master Surgeon operating upon a case of fistula in ano, is copied by the kind permission of the Trustees of the British Museum from a beautiful copy of Arderne's works preserved as Sloane MS. 2002. This manuscript was probably made in the early part of the fifteenth century for some noble patron.

SURGICAL PATHOLOGY OF THE PERIPHERAL NERVES.

By Captain SYDNEY M. CONE, M.O.R.C., U.S.A.

Since being placed by Colonel Sir Robert Jones in charge of the pathological department of Alder Hey, in June, 1917, all the knowledge of surgical pathology at my command, aided by valuable work done by others, has been utilized in an endeavour to solve the problems of nerve regeneration in war injuries of the peripheral nerves. To this end we examined macroscopically and microscopically tissues from more than two hundred cases.

Material from autopsies on fœtuses, adults, and guinea-pigs was used in studying the normal anatomy of nerves. Animal experimentation was carried out to show that the peripheral end of a torn nerve grew actively, and at the same time to give us an idea of the rate of growth. Nerve stretching and compressing experiments showed how one of the unsettled anatomical points (the Schmidt incisures) could be well explained, and also why the 'barbed,' 'beaded,' or conical appearance of the larger fibres was more commonly seen in nerves compressed and stretched in scar tissue than in normal nerves. They suggested, further, that these conical divisions of the nerve fibres, corresponding to the Schmidt-Lantermann incisures, had a physiological purpose —the continued insulation of the nerve when under stretch or pressure in normal movements. The distinct outlining of these divisions (conical segments) was best demonstrated by the neurokeratin stain.

The embryo and animal nerves also demonstrated that what we invariably saw in our pathological specimens as an axis-cylinder sheath was a normal structure.

By the animal experiments we were able to prove that the varicose and irregular branching appearance of the excised nerves indicated the youngest nerves, and that those with conical structures were older. We were also able to show that transplanted nerves grew about foreign bodies such as suture material—a fact which was also noted in the actively proliferating fibres in the pathological specimens. The transplanted nerves grew also in the presence of infection, a thing which we rarely noted in the human specimens.

One of the evident facts seen in our great amount of material was that nerves grew more readily in fat than in muscle; this was also demonstrated in the guinea-pig implants. That the blood-vessels, both active and thrombosed, were a common leader for the nerve fibres was noted in both the pathological material and in the guinea-pig experiments (*Figs.* 419, 420, 421). Granulation tissue, too, was demonstrated to be a fertile field for young nerve growth, the fibres following the vessels (*Figs.* 418, 447, 453).

The neurotropismus effect of neighbouring nerves on a cut or torn branch was proved when, in a specimen transplanted at some distance from the anterior crural nerve, new branching varicose tendrils were seen in granulation tissue growing about the crural nerve.

A negative result noted in the case of transplanted growing nerves likewise teaches a lesson. In none of the guinea-pig growths was there a tendency to dense formation of 'nerve callus,' such as occurs in the bulbous endings in scar tissue. No scar tissue formed in the experiments, and consequently the newly formed nerves were always seen as separated fasciculi or branching tendrils. It looks as if opposition to growth tends to make the nerve fibres more compact in arrangement, while not retarding their life properties greatly.

Some of the notable conditions in the pathological specimens concern the growth and the degeneration of nerves, vascular changes, phagocytosis, the character of connective-tissue formation in and about the nerves, the involvement of fat and muscle in nerve proliferation, the rate and location of nerve growth, the relation of nerve to enwrapping materials, the question of foreign bodies in nerves, the percentage of nerves in various parts of the excised nerve, the method of spread, and the age of nerves. These will be discussed in relation to the various portions of the excised nerve from which the section was taken, whether the central or peripheral end, the middle portion (usually the obstructing scar), or the surrounding adhesions. Much of interest to the histologist may be observed in the pictures from these different portions, in which young fibres will be seen.

Some of the most interesting findings refer to the question of nerve growth and degeneration in the distal end of a nerve completely separated from its spinal centre. The term 'nerve callus' will be seen to deserve its title, in specimens taken not only from bulbous ends and side bulbs, but also from within the nerve substance and from adhesions.

The phenomena occurring in a nerve graft will be found to be of interest. How sutures are taken care of will be seen in the guinea-pig experiments. That foreign bodies are no insuperable obstacle to new nerve-formation is demonstrated in many of the sections (***Fig.*** 418).

METHOD OF OBTAINING MATERIAL.

The average time after injury before the patient came to operation was about eight months. A few were operated on three months after the trauma, others two years later. Most of the nerves were injured by shrapnel or bullets; some were torn by splintered bone; others were indirectly involved by secondary changes in surrounding tissues, whether bone, skin, or muscle, owing to adhesions pressing or dragging on the nerve.

The entire area of apparently changed tissue—nerve and surroundings—was excised *en masse* until good tissue was supposed to be left behind. The nerve-ends that were sutured are represented in our pathological descriptions by the letters P and D. P represents the proximal or central clean-cut section across the nerve, at a point where the surgeon thought he had good 'soft' normal nerve to suture to D, the distal or peripheral end, where the surgeon made a clean cut across the nerve at a point nearest its end-organ, whether skin or muscle. At the latter end also incisions were made across the fibres, or whatever was left by the bullet's ravages, until a soft, supposedly 'normal' nerve tissue was reached; of course we understand that at D real normal original nerve could not be reached in a badly torn specimen—torn enough to require

suture—for nerves degenerate throughout the distal portion as soon as disconnected from their spinal centres. What is described as D is the piece adjoining the distal end which the surgeon unites to the other end P.

Gross Appearance of Tissues.—The worst tissue is usually seen about midway between P and D, being where the surgeon had great difficulty in freeing the conglomerate mass of nerve, muscle, and scar tissue from surrounding tissues. This we label M; it lies between two bulbous masses, the bulb nearest P usually being the larger; it often appears like ordinary scar tissue. This tissue of the bulb is very hard, and grayish-white in colour; the cross-section is at the first view homogeneous, but careful examination will reveal a fine mottling, due to a slight translucency of innumerable fine gray points. This is what we call 'nerve callus,' and will be shown to be made up of great numbers of fasciculi of very young nerves, intertwining, and separated by connective tissue of varying amount and density. The figures show that the nerve fibres in every case exceed in amount the mass of connective tissue, and van Gieson's stain corroborates this (***Figs.*** **430, 431**).

When the nerve trunk is almost or completely severed, the proximal end is usually bulbed; the distal end is sometimes bulbed, but otherwise is pointed or jagged.

Sometimes, when the surgeon's dissection is completed, there may be seen nothing but a dense white constricted cord of tissue directly continuous with the nerve trunk, improving gradually in appearance to the point where the damaged nerve was cut at P and D.

There are various grades of constriction and jaggedness of appearance of the exposed old nerve, according to the amount and density of the adherent constricting scar tissue.

The section across the nerve at the central end, left for suture to the peripheral segment, seldom appears so definitely marked by bundles and so well defined by endo- and perineurium as normal nerve. Seldom do the bundles protrude on pressure as so many comedo-like excrescences, but there is a translucency about the definite bundles, due to protoplasmic and nuclear increase. Instead of the normal milky-white (Sir Renfrew White) definite lines or dots or masses of nerve funiculi, there is a pinkish-gray gelatinous appearance, as of a more vascular, proliferating, cellular nerve (the cells of nerve fibres, connective tissue, and blood-vessels being involved). Often one is compelled to suture a proximal end that has only faint markings of bundles—the proliferation of young nerves and connective tissue in the endo-, peri-, and epineurium so interlacing with the old bundles as to keep them homogeneously massed together. They are grayish-pink or grayish-white according to the preponderance of vascular or connective tissue.

The distal cut section is more commonly a homogeneous grayish-white mass, but is very frequently marked by funiculi—resembling the proximal section in every respect.

Not infrequently, after relieving the nerve of lighter adhesions, it is seen spindle-shaped, and grayish-pink or grayish-white in colour, depending on the vascularity, fibrous increase, or nerve proliferation in this symmetrical bulb. Again, a single knob, more or less irregular, may be found. Two knobs (side

bulbs) separated from one another by dense white connective tissue frequently indicate where a bullet cut through a half or a third of the diameter of the nerve, leaving the torn fibres to recoil and grow as bulbs of 'nerve callus.'

The study of this nerve callus, of the scar, the sutured ends, and adhesions, has been carried out by every available means. We have been most careful in marking the specimens to avoid confusing the P and D ends. A suture with a label carrying the number of the specimen was tied at the proximal end, and the specimen was immediately placed in 10 per cent formalin solution; any delay vitiates the results. Sections were made transversely and longitudinally from the proximal end (P), the distal end (D), and the middle (M) of the excised nerve, and from surrounding adhesions (Adh.).

METHOD OF STAINING SPECIMENS.

After six days' hardening in formalin (10 per cent), the pieces were carried through 80 per cent, 90 per cent, and 95 per cent alcohols, 100 per cent alcohol and ether (equal parts), thin celloidin and thick celloidin (one day each). They were then placed on blocks and cut 15 to 20 μ thick, preserving the sections in 10 per cent formalin.

The stain used was one devised by the writer, and is most valuable in demonstrating the youngest tendrils and showing the finest structure of the nerve fibres. It differentiates nerves from all other structures very definitely. Neurokeratin, the fibres' most important and most constant element, takes a brilliant mauve colour against an unstained connective-tissue background.* Blood-cells are brown, nuclei pink, muscle pink, and fat unstained. Keratohyalin and the inner lining of hair sacs alone take the mauve colour. This is an interesting comparative embryological and histochemical fact, for nerves are, like skin, derived from the epiblast.

The method may be summarized thus: Water 1 minute, carbol fuchsin (Ziehl-Nielsen) 10 minutes, water 1 minute, osmic acid (10 per cent) 5 minutes, water 1 minute, acid alcohol (2 per cent) 10 seconds, water 1 minute, alcohol (95 per cent) until colour ceases to come away, alcohol (100 per cent) and oil of cloves alternately until the section appears deep pink and translucent, xylol 2 minutes; mount in canada balsam.

This stain may be used very profitably in the study of all tissues except connective tissue. Even in the case of connective tissue we may, by modifying the length of time in osmic acid, get a deeper stain of the nuclei and connective-tissue fibres. A great deal of the value of the method depends on the proper handling of the acid alcohol. The thicker the specimen the longer must it be decolorized in acid alcohol. One must not forget that the decolorizing is continued in the alcohols used to dehydrate preparatory to clarifying in oil of cloves and xylol.

This method is not designed for material hardened in other agents than formalin, nor for paraffin work, yet I have manœuvred on occasions so as to get fair results when compelled to use such unsatisfactory material. Alcohol and picric acid specimens were improved by leaving them twenty-four hours

* Egg membrane, which contains much keratin, takes the neurokeratin stain deeply.

in formalin. Paraffin sections stain more advantageously when chloroform is used to dissolve the paraffin, but the results are uncertain at best. Frozen sections give excellent results.

Although the neurokeratin stain shows the nuclei fairly well, I found that the method used by Howell and Huber was better adapted to the study of the multiplication of the nuclei of Schwann's sheath and of protoplasm. Here I used picric acid fixation and Boehmer's hæmatoxylin as staining reagent. Many sections were stained by Stroebe's, van Gieson's, Bielschowsky's, Weigert's, and Williamson's methods. I used free hand sections and teased specimens in glycerin mounts; but as soon as the carbol-fuchsin–osmic-acid (neurokeratin) method was developed, I ceased all other ways of staining.

I found that the gentle teasing of the specimen when on the slide in xylol ready for balsam, helped me to see tendrils in scar tissue which might otherwise have been overlooked. I also found that tendrils could be teased and followed for 4 to 5 cm. after the tissue was hardened in formalin. Thus one was able to stain the specimen, which could not have been done if Kühne's sulphuric acid 'cooking' method had been used.

Referring to some irregularities in the staining of the sections, I would like to quote what Roussy and L'Hermitte say about the sensitiveness of nerves to chemical changes: "Nerves are easily modified, and are not readily studied post mortem, because of chemical changes. They little resemble live ones. It is necessary to use the same technique in making a comparison of normal and pathological nerves." I found that with similar specimens, treated by the same method, but varying the time in one or another reagent, the entire nature of the stain was changed. In the neurokeratin method, the nuclei will frequently stain deep-pink in very cellular specimens, the nerves not showing at all; if we now vary the length of time in the acid alcohol, we reverse the result. This fact was particularly noticeable when using aniline-oil fuchsin, osmic acid, and ammonia.

This same method (neurokeratin stain) was used in the case of many surgical pathology specimens in order to determine their nerve contents, as well as more definitely to discover the capacity and limitations of the stain. Some of the nuclear changes in relation to the axis cylinders and myelin, noted by Howell and Huber in their picric-acid–hæmatoxylin method, were finely shown by the stain. It looked very much as if the nuclei were transformed directly into the new fibres. Bethe and Bowlby also made this observation. It is not an axis-cylinder stain, yet the youngest fibres take a homogeneous mauve colour, as seen in the five-days-old varicose tendrils and bulbous tips growing in the granulation tissue and muscle of the transplants in the guinea-pigs (*Figs.* 449, 450). As seen in the pathological material (fibrous scars, adhesions, bulbs, and newly-formed nerve-tendrils in old fibres), the mauve stain outlines by parallel fine lines a pink centre in fibres 2 to 3 μ wide. When the tendril is narrower or younger, the colour is not in parallel lines, but is a homogeneous single line, bulbed here and there (*Figs.* 438, 440, 441).

Modifications in Staining and their Significance.—Not infrequently I have been unsuccessful in staining young fibres in very cellular tissues. Repeated efforts with modification of the exposure to acid alcohol were successful. Kennedy has had a similar experience (1904). Similarly, when using

aniline stains with ammonia, I not infrequently noticed that, of several sections (all nerve-containing) treated by the same process, one might be nicely stained while another was not stained at all. Roussy and L'Hermitte explain this by the exceeding sensitiveness of the nerve to chemical changes. The specimens were not chemically alike. I think that much of the misunderstanding of laboratory workers comes therefrom. Bethe goes so far as to say that when a fibre is acid-fast it is physiologically functioning. I have no doubt that others will have some trouble with the neurokeratin stain until they learn the proper use of the acid alcohol. I never learned to use Stroebe's aniline blue stain; Kennedy, too, had to modify it to suit himself. Because one does not see all structures present with a special stain, it does not follow that another method may not succeed in demonstrating more. It is a mistake to say, after the use of only one method, that other investigations are all wrong.

I think, with Roussy and L'Hermitte, the success of nerve staining depends on the immediate placing of fresh tissues in the hardening agent. Chemical changes take place very rapidly in nerve tissue.

HISTOLOGY OF NERVES.*

Axis Cylinder.—This I regard as a homogeneous material in a sheath of neurokeratin. It has been described as a fluid; a glassy jelly-like substance which forms granules (Arndt); a fibrillar substance (Bethe, von Bungner); it is composed of discs (Mitchell). Ballance and Stewart describe the young axis cylinder as beaded and sinuous, remaining immature until united to the axis cylinder of the central stump. I find a sheath about the axis cylinder at a very early age—even in its varicose state. That it requires nerves from its own central stump to cause it to reach maturity can hardly be the case, for Langley and Ranvier showed that other nerves can make connections with the cut nerves. Arndt says: "The axis cylinder is a cell body or row of such cells drawn out into a thread . . . a mass of protoplasm modified into a ground substance and granules surrounded by a sheath." The normal diameter is said by him to be 0·5 μ. The ground substance impregnates its surface covering, and this is neurokeratin.

Myelin.—This is said to be an insulator of the nerve (Halliburton, Howell, Moynihan). Howell and Huber see a possible relationship in the disappearance of the nuclei and the myelin formation. Kolliker states that the myelin formation is influenced in some way by the nuclei.

I have used the stains by means of which the myelin was studied by others. With my stain the adult myelin structure in the medullary sheath is outlined quite clearly. Myelin is hard to see or to stain in the fibres 1–3 μ in size. At the youngest period it appears as if there is no chemical differentiation of neurokeratin and myelin. The youngest (5 to 8-day) fibres stain homogeneously a deep mauve with the neurokeratin stain.

Joseph demonstrates an intimate blending of the neurokeratin network of myelin and axis cylinder. Kuhnt describes this as forming an axis-cylinder sheath 0·1 to 0·15 μ thick. Tuckett believes that there is neurokeratin in the axis cylinder as well as in the medullary sheath. Kühne first described the neurokeratin framework of the medullary sheath.

Nageotte states that "myelin formation indicates maturation of a nerve (young neurites); they cannot function until myelinated." (See Howell and Huber as opposed

*Fuller details of this work will be published in the forthcoming number of the *Journal of Pathology and Bacteriology.*

to this view.) He states that there is an outer and inner myelin sheath (medullary and axis-cylinder sheath). Kennedy, who has done much to clear up the uncertainty surrounding our knowledge of nerve growth, writes of a "resting stage" of the young nerve fibre. At this stage, when it has no central connection, it does not acquire a thick myelin coat. It remains small for months, though "all the parts are represented." My work agrees with his findings. The nerves are seen in all my specimens from two months to two years after injury, even where they are only 1 to 3 μ in width.

Fleming, writing of the bulb 'neuroma,' says that the new fibres find their way with ease through the dense matting of fibres. The myelin suffers more than the axis cylinders.

Myelin Globules ('Vacuoles')—Schäfer describes a network of neurokeratin dividing the nerve irregularly as if by partitions. This framework is responsible for the so-called 'vacuoles' (globules of myelin), round or oval bodies outlined by a faint mauve line (neurokeratin), which I find invariably in medullated nerves. They are seen in the nerves of fœtus and adult, human and animal. These globules are well demonstrated in *Figs.* 408, 409, where the neurokeratin is deeply stained. Tinel refers to them as a 'gonflement' of myelin in the nerves, "making them looked vacuolated," but does not refer to the neurokeratin framework as responsible for their appearance. Tuckett and Joseph refer to the neurokeratin network of the medullated sheath passing on further and entering the axis cylinder. Ingebrigtsen refers to the fat-like globules (myelin) embedded in varicose accumulations of protoplasm located as a rule next to the nucleus. This was demonstrated by him in young nerves grown in Ringer solution. Arndt refers to the globules as occurring in atrophic and hypertrophic nerves.

The vacuolated appearance is more common in actively growing nerves. I find them in the nerves of the fœtus and in eight-day growths in guinea-pigs. There is no cause for confusing these bodies with degenerated material. They do not stain with the neurokeratin method—the border alone is outlined. I have seldom been able to demonstrate them in nerves from autopsies held after several hours, owing to chemical changes in the nerve. The balls that appear in degenerated nerves, called 'myelin balls,' take a deep black stain and are not outlined by a delicate mauve-coloured framework.

Conical Segments.—Adult fibres, 6 to 12 μ wide, invariably appear under the low power as barbed, beaded lines. With 350-diameter magnification one sees regular rows of cone-shaped mauve-coloured objects closely following one another; 10 to 40 μ is the usual length of these conical segments. Their bases stain deeper than their apices, and these latter seem truncated to fit round the central content (axis cylinder) of the fibre. The ending of this conical portion is cylindrical. It may be seen as a circle in cross-sections cut a little obliquely (*Fig.* 406). Similarly, the more deeply stained base of the cone, apparently attached to the sheath of Schwann, appears as a circle in appropriately cut sections.

The relation of these objects to Schmidt's incisures and the axis-cylinder sheath was specially studied. All nerves above 4 μ in diameter are seen to be made up of conical segments corresponding to the space between adjoining Schmidt-Lantermann incisures. These are seen invariably in the pathological material. They have been studied in the nerves of embryos, normal adult nerves procured from amputated stumps and autopsies, and in guinea-pigs' nerves. They appear most definitely when the nerve has been stretched or compressed. This I demonstrated by stretching nerves of stumps and guinea-pigs, and placing them at once in formalin or osmic acid with control nerves (the neighbouring nerve or intact half of the stretched nerve). Slight post-mortem change will interfere with the most distinct outlining of the cones. The stretched nerve is seen, either in glycerin or after hardening, humped at regular intervals (40 μ) as if to receive the portion of nerve following it. In stained sections this gives an invaginated or intussuscepted appearance (*Fig.* 405), the intussusception corresponding to the location of the incisures of Schmidt, which may be seen in osmic acid-hardened specimens as unstained oblique lines passing from the neurilemma sheath to the axis cylinder.

There is no doubt about these cones being normal anatomical constituents of the nerve fibre (*Fig.* 440). Under the same methods of examination they always appear alike in similar conditions of age, size, normal or pathological state. I believe, with Howell and Huber, that the growth and degeneration of myelin in segments is regulated by the Schmidt incisures, which are the boundary lines of these cones. Their limitation is due to neurokeratin material. They are doubtless the means of insulating the nerve, as described by Halliburton, Howell, Moynihan, and others.

Experiments to show Nerve Segments.—Normal nerves were examined fresh, in salt solution, in glycerin, and after hardening in formaldehyde. A suture was fastened to each end, one of these being tied fast to one side of the mechanical stage of the microscope, the other being used to stretch or relax the nerve. Electric-light illumination demonstrated the incisures as bright lines, the surrounding tissue interfering with the ready passage of light. Two incisures pointing toward one another were selected for observation. As traction was made, the lines of light, which had originally reached the axis cylinder at an acute angle, seemed to approach from the neighbouring incisures, forming a cylinder of light for the greater distance between the original bases of the incisures. The bases could, however, always be seen as such. After stretching, the outer border of the fibre was seen to be humped at the bases of these cones of light, growing narrower at the part of the fibre corresponding to the more pointed part of the cone, giving an intussuscepted appearance. The nerves were stained after completing the experiment, and when they had not been overstretched or torn, elongated cones were clearly demonstrated. Seen in the pathological material, they differ in no respect from the above. They are not pointed, but appear as truncated cones. Golgi refers to them as funnels outlined by neurokeratin. They are always present in the wider (6 to 12 μ) nerves of our pathological material, and seem more distinctly outlined than in normal nerves. Schäfer pictures them in the 1916 edition of the *Essentials of Histology*.

They were noticed by us in our early work, but were not so systematically or definitely pictured until stained by the neurokeratin method. Ranvier refers to "renflements biconiques" occasionally seen. Tinel writes of nerve fibres as "hérissées d'épines," "barbelées" (barbed), when stained with silver nitrate. He evidently saw the stained incisures—the stain not penetrating along the entire structure. He says correctly that his barbs are incisures of Schmidt-Lantermann. Stroebe and von Bungner and many others are still disputing about the Schmidt incisures, questioning whether they be real or artifacts. I have no hesitation in agreeing with Schmidt, Schäfer, and Golgi. The photographs (*Figs.* 405, 406, 407, 408) demonstrate them well in longitudinal and oblique sections. The Schmidt incisure is the base of the cones or funnels. The incisures are usually pictured as narrow oblique lines placed every 40 μ along a nerve and penetrating as far as the axis cylinder. They go farther, as my stretching experiments demonstrate. The stained specimens show these lines continued alongside the axis cylinder as a sheath (*Fig.* 407). They are more faintly stained as they approach the next cone base, but never completely lost to view. I originally described them as truncated cones, but think Golgi's term 'funnel' is a better one.

We thus have an explanation of the structure of the incisures of Schmidt, Tinel's barbs, and the axis-cylinder sheath, all in one. All belong to the neurokeratin framework, which also is responsible for the 'vacuoles' when it sends finer branches amid the myelin sheath (Schäfer). The length of these cones varies under changing conditions of stretching or pressure. They are regularly placed, and measure 40 μ in length as a rule, but I have seen them, symmetrically placed, measuring 10 μ from base to base. I have stained them in many different ways, but in none of the specimens is the entire body of the cone demonstrated so clearly as in those stained by the neurokeratin stain.

Golgi states that in order to demonstrate these 'funnels' the nerve should not have been stretched. In my original observations on autopsy material, I stated that "too much stretching defeats our object, especially in the material removed at

autopsy, for in these cases there is a modification of the tissue produced by post-mortem changes."

Varicosities.—The young nerve is recognized by its size, shape, and spiral winding or branching from another fibre. In its youngest form the myelin coat has not as yet been added. It is the characteristic varicose appearance which is most striking. Many observers have studied these peculiar irregularities. Some look upon them as evidences of degeneration. With the neurokeratin stain, the tendril, when degenerated, is broken, with sharply angular outlines, it stains irregularly (not mauve), and is granular. I have seen enlargements of the tendril due to the pressure of a neighbouring nucleus. Ingebrigtsen pictures such fibres. Arndt's explanation is that the imbibition of fluid may sometimes cause the irregularity. This may exaggerate the condition, for I find this appearance most marked in hæmorrhagic and œdematous nerves. Schmidt thinks that gas causes the swellings. Tuckett believes that poor hardening is responsible, and that they are post-mortem artifacts. Wilson says they occur normally at points of branching, on the axis cylinder or where the fibre is more subject to external influences. They are not artifacts as a rule. Ingebrigtsen photographed them growing in vitro, and they are seen in sprouting tendrils of young branching nerves in my guinea-pig transplants (*Figs.* 444, 446, 449, 450, 457). It is quite possible that the irregularity of pressure a delicate fibre is subjected to in winding through tissue of varying density may be one of the many causes of its unevenness of structure. The fibres are not always varicose. One often sees straight and varicose fibres in the same microscopic field.

NERVE DEGENERATION.

By the time our cases were operated on, the Wallerian degeneration had run its course. The myelin had gone through the fragmenting and balling processes, and been carried off by phagocytes or in the lymph stream as fat (MacDonald). Langley says that traumatic degeneration is seen up to 100 days. Kennedy says it may be many months before all the degenerated material disappears. Occasionally I have found black-stained balls of myelin in the old fibres four months after injury. Before myelin balls form, the cones become granular and stain irregularly. At this time protoplasm with innumerable spindle-shaped nuclei fills the old sheath-of-Schwann sac, now empty of its original nerve. Many young fibres are seen in this protoplasmic syncytium before the degenerate products have gone. This is readily understood if, with Nageotte, Kirk and Lewis, and Ingebrigtsen, we believe that regeneration depends on a preceding Wallerian degeneration (*Figs.* 410, 412).

In a recent case, constriction of the posterior tibial by a mass of dense cartilaginous connective tissue produced all the typical products of Wallerian degeneration in the portion of the nerve distal to the ring of tissue, a few nerves remaining intact; this was two months after injury.

Langley used methyl blue to stain axis cylinders. An hour or two after the nerve was cut, the axis cylinder stained a deep even blue. In ten days it appeared less regular. In twenty days it stained less deeply and the boundaries were not sharp. In thirty days there was no stain. He believes that neurilemma cells are phagocytic, absorbing the degenerated myelin, that there are different rates of degeneration in the different kinds of nerves, and that small nerves resist degeneration longest. Weir Mitchell, Remak, Bidder, Korybutt-Daskiewicz, Wolberg, Schiff, Howell and Huber, Phillipeaux and Vulpian, and Erb believe that the axis cylinder remains intact during degeneration of the medullary sheath. Neumann and Eichhorst hold that the axis cylinder undergoes changes, and fuses with the myelin to form a new nerve fibre. Erb joined them in this view later. Howell and Huber say: "Most writers think that the axis cylinder goes to ground with the medullary sheath." Degeneration occurs in the peripheral end after section. First it occurs in the segments (Schmidt-Lantermann's), then balls of myelin form.

Phagocytes.—My specimens show giant cells, epithelioid cells, pigment cells, and leucocytes, all acting as phagocytes. It has been said (Keen, Langley, Stroebe, Mott, Halliburton, and Edmunds) that the neurilemma-sheath cells act as phago-

cytes. Mott, Halliburton, and Edmunds note with others that later they join end-to-end like embryonic nerve fibres. Most observers look upon them as nerve cells (neuroblasts) with a specific function. When proliferating, they resemble connective-tissue cells so closely that it is impossible to distinguish them. It is in their quiescent condition, before and at the end of proliferation, that their elongated staff-shaped nuclei, containing more chromatin, may differentiate them.

When von Bungner said that 'wander cells' and leucocytes were seldom seen, he was dealing with experimental material. In work done in Kühne's laboratory on nerve degeneration, I not infrequently saw leucocytes engulfing myelin débris. It was not so common, however, as one would expect from what one finds in the removal of foreign material from other tissues than nerves. I never saw what I could call a Schwann-sheath cell acting as a phagocyte. Tinel says Schwann-sheath cells, connective-tissue cells, and leucocytes carry away the débris. In photographs by MacDonald representing fat removal in peripheral nerve degeneration, the globules as such are seen in septa between the bundles.

Neurilemma-sheath Cell-proliferation.—The most marked definite neurilemma-sheath cell-proliferation may be studied in the nerve fibres which have lost their normal contents by Wallerian degeneration. This involves the entire distal portion of a severed nerve, and extends as far as the first or second node of Ranvier of the proximal segment.

It is seen best in our early cases (three to four months), where there still is evidence of degeneration products, in the shape of myelin balls, in the nerve fibre. The appearance is that of a great number of protoplasmic circles with several nuclei in each. These circles are swollen, closely pressed together, and might be compared to an alveolar sarcoma with unusually symmetrical alveoli and a limiting circular wall (epineurium). When cut longitudinally, the nuclei are most prominently seen as spindles or elongated staffs, very closely bunched. Sometimes there is no evidence of protoplasm, in which case one is most apt to find new varicose nerve-fibres present among the nuclei. Rows of these nuclei look like fasciculi composed of nuclei instead of nerves—the old fibre delimiting the new fasciculus. This is exactly what happens, for I have followed such rows of nuclei along until there was seen a transition to young varicose nerve-tendrils. Again, my first stains showed no nerves, but repeated efforts demonstrated a few young tendrils among the nuclear mass.

In a 35-day transplant, such fasciculated rows of nuclei were seen to branch, and could be followed to a point where there were tendrils of varicose young nerves in place of the nuclei. The nuclei stained less well as one approached the area of nerve budding. There were still evidences of a few faintly-stained nuclei among the tendrils. These nerves were branched and bulbous at their ends, and appeared varicose—with deeply-stained bodies, half the size of a nucleus, attached to them. They were vesicular and deeply stained by turns. Some of these irregularities gave the appearance of nuclei flattened against one another at their ends—the junction being biconical and circular. (See Halliburton, Mott, and Edmunds, Ziegler, and Galeotti and Levi.)

The newly formed tendrils appear on cross-section as circles, 1 to 3 μ in size, homogeneously stained or as rims of mauve colour with a pink centre (*Fig.* 420). Thicker specimens may give the appearance of stamens protruding from a flower (*Fig.* 411). As the new nerve forms, the nuclei disappear (*Fig.* 450). Howell and Huber state that as myelin forms many of the nuclei go. They infer that it is possible for the nuclei to undergo a "myelin degeneration." I would suggest that it is much more likely from chemical analogy for the nuclei to be directly transformed into the nerve tendrils. Both contain a keratin element. Physiologically, too, they have their relationship, the nucleus controlling the trophic condition of the containing cell. Howell states that it is through the nucleus that the trophic (nutritive) influence of the nerve centre is transmitted.

The nuclei in most of my specimens are long spindles. They are very often staff-shaped (see Stroebe and Nageotte). They are better studied by Howell and Huber's method, in which the protoplasm about them is also stained as granular

lines, 1 to 2 μ in size, gradually tapering to a point and continuing for a distance of 80 μ. Frequently the nuclei look as though they were budding, and my neurokeratin stain shows a similar appearance, though not so distinctly. I think this question of nuclei in their relation to axis-cylinder growth will be well worth study.

I have never seen the ganglion-cell nucleus described by Gluck. Giant and multiple nuclei as described by von Bungner have occasionally been present. Eichhorst says that in degeneration of the nerve the nuclei change in shape from spindle to round.

We have never been able to trace a change from protoplasm into the formation of nerve fibres or myelin. We see nuclei in a wild state of proliferation in greatly increased protoplasm. The next stage noted is less protoplasm and more nuclei, the latter taking the form of the old fibre *en masse*. Then we finally see young tendrils crowded among nuclei and protoplasm, the nuclei much decreased in number, the protoplasm disappearing.

I cannot well see why Howell and Huber should think that Bowlby mistook nucleoli for axis cylinders. The nucleoli can seldom be well demonstrated in nerve work except by their own stain. In my work they are very faintly stained. All the round objects 1 to 3 μ in size which are seen stained mauve within the old nerve fibre are new nerves. Not infrequently the tendril has developed to such a size that one may see the pink axis cylinder in the centre of a mauve-coloured rim. Van Gieson's stain shows nuclei black, protoplasm brown, myelin and axis cylinder unstained.

Luciani, quoting from Ranvier, Vanlair, etc., refers to the arrangement of the neuroblasts of the neurilemma sheath in a chain, the nuclei being spindle-shaped. Benecke describes variously shaped nuclei. They always have a little protoplasm around them. Many of them are quite long. He describes them as being connected by thread-like processes when the nucleus itself disappears. This fibre now broadens, while a sheath gradually forms about it. His description of the occurrence corresponds with that of others (Galeotti and Levi), but his interpretation is different. Galeotti and Levi describe the proliferated nuclei of the sheath of Schwann as round or oval, containing more chromatin than normal. They were originally long. "The proliferating cells resemble embryonal cells in the development of nerves." Its stain differentiates this cell from a connective-tissue cell, and its action it that of a neuroblast. They used the salamander tail, as Harrison did, and grew young nerves which they saw form by a fusion of neighbouring cells. These were rich in nuclei, symmetrically placed. The protoplasm was hard to see, and finally disappeared, leaving the nucleus alone. Rows of granular material were now seen united as axis cylinders. Von Bungner describes the nuclear proliferation of cells of the neurilemma as at its height in five to eight days, one nucleus for each segment. He says, "These nuclei are surely of nerve nature, and must be called neuroblasts." Gluck describes rows of nuclei between young fibrils. Mott, Halliburton, and Edmunds refer to the elongation and multiplication of nuclei early in degeneration. They are arranged connected end-to-end, "looking like embryonic nerve fibres." They do not believe, however, that they form nerves.

NERVE REGENERATION.

All the material investigated showed new nerve growth in one or another part. The lowest percentage of nerve findings in either P, M, D, or Adh., was 82 per cent, in adhesions. Sometimes this included full-grown, old, good nerve trunks. I cannot imagine a case such as comes to the Alder Hey operating table not showing some young tendrils in the pathological specimen. These operations are delayed purposely until all danger of infection from the old infected wound has disappeared. In the meantime there has been a prolific growth of young fibres everywhere. It is not only from the main injured trunk we find nerves growing at various points (P, M, D, and Adh.), but like-

wise from other surrounding smaller nerves to muscle and skin. These are seldom considered. Langley and Ranvier pointed out long ago how experimenters (Vulpian and Bethe) overlooked the possibility of having cut other nerves than those experimented on, thus vitiating their results. I have seen small adult nerve trunks, as well as bundles of actively-growing young nerves, in the adhesions removed from about the scene of nerve severance.

Neuromas of Nerve Ends.—The nerve bulb, found at the end of the proximal segment, distal segment, on the side of a nerve, or as a cylindrical enlargement of the trunk, is the place where we may expect to see the most prolific growth. The same kind of growth and appearance is found here as is seen on the ends of nerves of amputation stumps (amputation neuromas). Alexis Thomson has enlightened us on this subject. Bowlby, Kennedy, Gluck, Eichhorst, and many others, have used the term 'nerve callus' to describe this young nerve material about the nerve ends. In 1887 Bowlby not only drew attention to the analogy between this nerve callus and bone callus, but thus early demonstrated new growth in the distal end.

It has been a difficult matter to convince many that there are fully formed nerves in either end bulb. Now it is scarcely questioned that these nerve callus masses are full of nerves containing axis cylinders. (Appended are photo-micrographs of nerve callus from various locations (*Figs.* 429, 430, 431, 433). Some are stained with the neurokeratin stain and also with Bielschowsky's axis-cylinder stain.)

The gross appearance of these wildly growing, coiling, twisting nerves is that of dense scar tissue. It is dense, grayish-white, hard, nodular (as a rule), and is most commonly seen at the ends of nerve trunks. It may be found, however, wherever the epineurium has been torn through to the nerve fibres. It is frequently situated between nerve trunks and in the adhesions near by (here it probably ends an overlooked injured skin or muscle branch). Not infrequently the homogeneous grayish-white surface of the cut section is mottled by pin-point dots or larger translucent grayish-pink areas of cellular nerves. It is also found extending about the nerve trunk 2 to 3 cm. from the end bulb.

I cannot add much to what Kennedy wrote about the microscopic pathology of these growing masses of nerve. I must accentuate the fact, however, that in all of my sections of nerve bulbs there was more nerve than connective tissue; as a rule they consisted of three-quarters nerve and one-quarter connective tissue and vessels.

The microscope demonstrates the homogeneous mass to consist of interlacing fasciculi of young nerves, the fasciculi varying in size from 10 to 50 μ in diameter. The nerves making up these small bundles are young varicose fibres 1 to 3 μ in size. Sometimes one finds larger ones mixed with these. The larger fibres are coned, and measure 6 to 8 μ. Where one sees larger fibres running parallel and bound together in bundles, they usually belong to the original trunk from which the others spread. As a rule this is seen to one side and away from the tip of the bulb. Sometimes they are found at the very tip, for the trunk not infrequently coils around as a whole before sprouting at the end.

The interlacing of the fasciculi is the most characteristic appearance, but we not infrequently find single tendrils growing wildly in the surrounding

tissue (*Figs.* 417, 438). They are varicose, bulbed at the end, frequently branch, and course in a spiral manner. The surrounding, supporting tissue is as a rule cellular, vascular, wavy connective tissue, not loose areolar tissue: it is rather compactly built—more so than one usually finds the case with cellular connective tissue. I take it that many of the spindle-shaped nuclei are nerve nuclei from the proliferating cells of the sheath of Schwann (see Tinel). There are always great numbers of nuclei among the fibres. Sometimes they are seen as staff-shaped nuclei, again they are spindle-shaped. This seems to depend on the stage of regeneration in which we find them. The varied description of these nuclei by competent pathologists must mean that their size varies greatly according to age. I have frequently seen them so numerous as to resemble a leiomyoma of the uterus, and Busse has also noted this.

I have not been able to make the distinction mentioned by Tinel between a true neuroma of the proximal stump and a glioma of the peripheral stump. This distinction was based on some of Nageotte's work. Since the publication of Tinel's book (1916), Nageotte has concluded that the fibres which he called neuroglial are really amyelinic axones (axis cylinders) from sympathetic nerves of blood-vessels; consequently the growth they form cannot be called glioma.

Van Gieson Stain.—This was used to demonstrate the difference between connective tissue and nerve. One specimen happened to be a very good one for the purpose. It was cut longitudinally through the entire exsected piece. The neurokeratin stain demonstrated the distal segment to be a dense mass of interlacing fasciculi of tendrils 1 to 3 μ in size, surrounded by many proliferating neurilemma-sheath cells with elongated nuclei. The proximal end was fibrous. With the van Gieson stain the nerves' side of the section (D) takes a brown colour; this is because of the great amount of protoplasm about them (nerves themselves do not take this stain). The fibrous-tissue (proximal) part of the section stains pink.

Rapidity of Growth.—The five-day and eight-day growths in guinea-pigs showed that the varicose tendrils could form fasciculi in this time. The fibres had wound their way into the skin and muscle at least 4 mm. distant from the implant. Ingebrigtsen saw the tendrils grow in vitro 500 μ in six days. Tinel says they grow 1 to 2 mm. a day.

How do Nerves Regenerate?—That the central end of a divided nerve is most active in regeneration is not questioned. Ranvier's original dictum that tendrils branch from the neighbouring nodes, two or three distant centrally from the cut, is accepted. Many writers state that they have seen the peripheral end regenerate also. The questions in doubt are:—

Does the distal end regenerate? If so, do these fibres mature? What causes them to mature? Can they mature without a spinal-centre connection (i.e. by autogenesis)?

What do new nerves come from? From neurilemma-sheath cells, or directly from old fibres? From ganglion cells? From connective-tissue cells? From leucocytes? From red blood-cells? From old fibres in which axis cylinder and myelin sheath have fused to form a new fibre?

Do nerve grafts grow *in situ*? Do catgut or other grafts carry anything which can form new nerves? Do the Schwann-sheath cells wander?

What action has the protoplasm of the neurilemma-sheath cell in nerve regeneration ?

Is chemotropismus (neurotropismus) a factor in stimulating new growth ?

Some of these questions will be discussed briefly.

Does the Distal End Regenerate ?—Kennedy, Bowlby, Langley, Howell and Huber, Ballance and Stuart, Tizzoni, Catani, Galeotti and Levi, von Bungner, Mott, Sherrington, Wolberg, Korybutt-Daskiewicz, Hertz, Neumann, Wieting, Sedgwick, Eichhorst, Benecke, Bethe, Weir Mitchell, Vulpian and Phillipeaux, Hjelt, all believe that it does. Many of them raise the question whether central connection is necessary for such regeneration. Some believe that the nerves will become what Howell and Kennedy call embryonic fibres, and go no further until connected with spinal centres. Some believe that the nerve goes on to maturation without spinal (central) connection. It is difficult to find anyone who holds that there is no regeneration in the distal end. The spinal connection is easily explained. Langley and Ranvier pointed out the readiest method when they disproved Vulpian and Bethe's proofs of autogenic new growth to maturity. Their evidence indicated that neighbouring nerves of skin or muscle made the central connection. Langley says non-medullated fibres may make the connection.

The author has demonstrated four methods of connecting the distal with the central or spinal fragment, thus giving the embryonal nerves an opportunity to mature : (1) By neighbouring nerves, torn at the time of the original injury ; (2) By a strand of undamaged, overlooked nerve still connecting the central and peripheral stumps ; (3) By nerve fibres which have worked their way through the scar ; (4) By adhesions carrying nerves around (bridging) the scar.

In Woolsey's opinion the fact that the axis cylinders of the spinal cord do not regenerate when cut, supports the view that the peripheral end regenerates from neurilemma cells—there being no such cells in the cord, regeneration after section is not possible.

Baer, of Johns Hopkins University, in a personal communication, informs me that he finds that the Schwann-sheath cells die in anterior poliomyelitis. This might partly explain why the nerves do not recover in this disease. This evidence has its negative value in helping to prove the regeneration of the distal end from the neurilemma-sheath cells.

Do the Distal Fibres Mature ?—In 86 per cent of the specimens from the distal end stained by the neurokeratin stain nerves were seen. In the majority of cases they were in fasciculi. Sometimes bundles of full-grown fibres had formed. Frequently single varicose tendrils were seen, following blood-vessels, or discrete in cellular connective tissue. Bielschowsky's axis-cylinder stain demonstrated axis cylinders in every case when it was used as a control. Not only do these axis cylinders stain well, but, as my guinea-pig transplants show, they proliferate actively.

There are a few cases in which sufficient time has elapsed for the results of operation to appear. In some of these—the earliest good results—both ends contained only fasciculi of fibres 1 to 3 μ in size. A future report will compare clinical results and pathological findings.

Can the Distal Fibres Mature without Central Connection ?—Among those

who believed in such a discontinuous formation of nerves were Remak, Heller, Benecke, Eichhorst, Neumann, Hertz, Leegard, von Bungner, P. Ziegler, and Virchow. Bethe thinks disconnected fibres can mature, though he admits that they are more likely to reach full development when stimulated by central association. He describes degeneration in many of his 'autogenic' nerves when they are left too long disconnected. He found it necessary to use very young animals in order to get good results.

Whence do the Young ('Embryonal') Nerves Come?—We shall not discuss the theories of connective-tissue, red blood-cell, and leucocyte origin promulgated by Benecke, Hertz, and Hjelt (who considered the nuclei of the neurilemma to be connective-tissue cell nuclei). Most of those who believe in a discontinuous origin of nerves, ascribe their beginning to cells of the neurilemma sheath. Hjelt, Stroebe, Kolliker, and Benecke take these to be of connective-tissue origin. Galeotti and Levi can distinguish them from connective-tissue cells in the salamander. Von Bungner considers them to be nerve cells. Ziegler and Gluck hold them to be ganglion cells, and Gluck calls the mass "nerve granulation tissue." Whatever they be called, the writers were all doubtless describing the same thing. That the nuclei and cell protoplasm are of varying size and arrangement at different stages in the proliferation is noted in my own experience, as well as by Stroebe, Benecke, and von Bungner. These authors observed the varying size and shape of the nuclei of the neurilemma sheath. The protoplasm, in order to form the irregular masses giving origin to myelin (Howell and Huber), and to form the strands and syncytium (Nageotte, von Bungner, Kirk and Lewis, Ingebrigtsen), must alter its size considerably.

It has also been pointed out by Eichhorst, Hertz, Mott, Halliburton, and P. Ziegler that the nuclei are arranged in rows, seeming to be connected or fused end to end. This arrangement was seen in a number of our sections in an apparent transition to young fibres. Eichhorst refers to a number of workers in nerve pathology who ascribed the origin of the nerve to a fusion of nuclei—Bowlby, Virchow, Nasse, Waller, Laveran, Robin, Einsiedel, Oehl, Luys, Weismann, Foerster, and Bruns.

Kennedy, Kirk and Lewis, Ingebrigtsen, and Galeotti and Levi suggest that the proliferating cells of Schwann's sheath grow into the scars of divided nerves. That the neuroblasts from the neurilemma sheath carry (by migration) the nerve growth to other parts, is indicated in my guinea-pig experiments. *Fig.* 444 shows two distinct growths, one near the scar, another an inch away. In this and other guinea-pigs, new growth is demonstrated in the fat about lymph glands (*Fig.* 452).

If the neuroblasts wander, the answer to the question whether grafts are of value is simplified.

Finotti, Keen, Gluck, and Sydenham have successively bridged large gaps between nerve ends with catgut or silkworm gut. Nageotte determined that a homoplastic graft of nerve differs from a heteroplastic piece only in being a little faster in myelinization. He grafted with good results nerves preserved in formalin or alcohol.

Langley says that all the medullated fibres in the peripheral ends of cut nerves are fibres which have become connected with the central nervous

system. If autogenic regeneration of fibres occurs, every one of them must have become connected with the central end of some fibre. This he states in criticism of Vulpian and Bethe's autogenic growth theory.

The neuron, according to Bethe, is not a functional unit—the ganglion cell is not essential. "After degeneration of the axis cylinder, the cells of Schwann's sheath proliferate, forming much protoplasm. An axial strand and peripheral sheath form—if one prevents healing of the cut ends of nerves in young animals a perfect regeneration may be forced." The formation of the axial strand from the protoplasm of Schwann-sheath cells is commonly accepted. Vulpian says (1859), "Transplanted nerves grow autogenically," and later (1874), "A nerve may get its trophic influence in other gray matter than that of the nerve to which it belongs."

Adult and Young Nerves.—It is obvious that a differentiation of nerves according to age might be of value. Data obtained from experiments on guinea-pig transplants and torn nerves, pathological material operated on at varying periods following injury, fœtal nerves, and normal nerves from autopsies, lead to the following conclusions.

When nerves are arranged in bundles with parallel fibres, they may be expected to contain full-grown fibres. Many of our specimens demonstrate, however, that these old bundles have lost their original contents, which are replaced by nerves in various stages of new growth. These bundles are never so compactly built as normal ones—i.e., with nerve fibre apposed to nerve fibre, showing as well-defined circles 10 to 12 μ in size, with a scarcely appreciable endoneurium. They commonly appear as a nucleated protoplasmic mass divided more or less indefinitely into swollen circular areas corresponding to the original fibres. There is an increase in endoneurium in all stages of regeneration, from connective-tissue cells to dense connective tissue, separating the individual protoplasmic nucleated masses, which replace the old fibres.

In a later stage one may see nuclei in such profusion as to simulate a spindle-cell alveolar sarcoma, except for the fact that the wider view shows the thickened peri- and epineurium defining the nerve. Such masses stain best with Howell and Huber's picric-acid–hæmatoxylin method, but it is by the neurokeratin stain that one can be sure of what these nuclei and protoplasmic masses represent. By this method one not infrequently sees varicose mauve-stained tendrils among the nuclei. These increase in number as the protoplasm and nuclei decrease (see Howell and Huber's work referred to later, also Kirk and Lewis's reference, and others), until we see bundles made up of fasciculi of ten to twenty tendrils, each fasciculus representing an old nerve fibre (*Figs.* 410, 413). The fasciculi contain the finer tendrils 1 to 2 μ in width, and fibres 4 to 6 μ in width, with conical segments 20 to 40 μ long—these latter are more fully-grown fibres which will soon reach their full size, 10 to 12 μ.

Many of the fibres must degenerate from the pressure of growth, and this can indeed be demonstrated by the irregular staining and breaks in outline of many young fibres.

In some of our specimens cut longitudinally we can trace fasciculi of elongated nuclei to a point where mauve-coloured tendrils are seen. At the same time there is a marked decrease in the number of nuclei—"as the new nerve forms many of the nuclei disappear" (Howell).

In the guinea-pig experiments the varicose bulbed appearance of the young branching fibres is well shown.

In loose, non-restraining tissue, the spiral winding of the fine young tendrils helps one to pick them out. Discrete twisting young fibres can be seen between muscle bundles (*Fig.* 457), around hairs (*Fig.* 451) and along blood-vessels (*Fig.* 453) in the photomicrographs of guinea-pig transplants. One of the pictures shows what looks like a direct transformation of nuclei into nerve tendrils, portions of nuclei and entire nuclei remaining attached alongside the fibre. Some of the points of deeper staining resemble the bases of the cones seen in adult nerves, and look as if two nuclei might have fused at this point.

Sheath of Schwann.—It has appeared to me that as the new tendrils grow discrete in the connective tissue they pick up a fibrous sheath. The Schwann-sheath nuclei which remain from the great mass that were present a short time before, are seen resting against this new sheath like a secondary fixture and belonging to the nerve proper. This same method of acquiring a neurilemma sheath occurs to those tendrils which are in fasciculi, the connective tissue cells being seen only in the larger fasciculi. They do not acquire a sheath so long as conditions of pressure are such as to prevent new connective-tissue growth (e.g., in dense nerve-callus).

Neurotropismus, and the Trophic Influence or Direct Action of Protoplasm in giving Direction to Nerves.—There are certain influences causing nerves to grow or take a certain course. We have referred to the physical effect of the guidance of blood-vessels and the blocking by scar tissue. Vanlair used bone pathways to direct their growth, believing with Ranvier that nerves follow the line of least resistance. Forsmann, investigating the phenomena of nerve growth, noted: "It takes many fibres to give a notable functional result. Many err on their way (following section). They are seen in the surrounding tissues at the cut, and further central. They can err even after crossing the gap. It is remarkable that so many continue along the old nerve path." He experimented with the idea of solving the problem. In one of his experiments, in which he placed the nerve in a 'straw' tube with brain at the other (upper) end, the nerve grew toward the brain. In the next experiment no brain was placed at the opposite end of the tube, and only a few fibres found their way up the tube. This is due to what Langley calls neurotropismus (chemiotropic influence). Ingebrigtsen, Kirk and Lewis, and others interpret it as indicating that the syncytium of protoplasm from multiplying neurilemma-sheath cells guides the nerves. Bidder long ago stated that cut nerves, when sutured, break away to join their mates. Elsberg calls attention to a most interesting phenomenon which doubtless has a similar explanation. If a nerve to a muscle be cut and be implanted with another (foreign) nerve into the muscle, the original nerve alone makes connection.

These facts will explain many of our observations. Note in *Fig.* 450 the young nerves in granulation tissue around the anterior crural nerve some distance away from the original implant. One specimen pictures a nerve growing in a thrombosed vein, with small nerve trunks on both sides. Great numbers of young tendrils are seen in the walls of the vein, doubtless attracted by the neurotropic influence without.

Keen, Gluck, Finotti, and others use catgut to bridge gaps. Here both Vanlair's and Forsmann's influences are concerned in guiding the nerve. Nageotte has more recently made use of nerves preserved in formalin or alcohol to help the two ends meet.

Luciani refers to the neurotaxis (chemical stimulus) of degenerated nerves in the growth of young tendrils. Others, notably Ingebrigtsen, have shown the great influence of Wallerian degeneration in stimulating the sprouting of nerves. Ingebrigtsen found that he could not get transplants to grow in Ringer solution before they had been cut and left *in situ* five days. In my guinea-pig experiments the transplants grew at once. Vulpian's implants did not begin to grow for six months. My implants were taken from old injured nerves that had gone through Wallerian degeneration and had begun new growth. Vulpian transplanted normal nerves. Nageotte, in writing of the 'gliomata' at the end of a cut nerve, stated that they contained no axis cylinders, but that the fibrils possessed 'tropismus' like nerves. Since then I judge he has accepted this as an additional proof that he was not dealing with neuroglia, but with real nerves and axis cylinders. He now says that what he originally called neuroglia fibres are "amyelinic axones."

The Fibrous Scar.—The scar that is said to be the *bête noire* of the surgeon is between the ends of the severed nerves. Its centre is sometimes called 'chéloïde nerveuse,' a name given it by Dejerine. I find it no different from any other scar tissue, except that it seldom becomes sclerotic. Densely-growing tissue of any kind makes it difficult for nerve to pass through. Nerves may be turned aside when their ends reach an already prepared buttress. It is quite natural that unless the nerve fibres have grown *pari passu* with this connective tissue, an entering wedge will be next to impossible; it must be made when the tissue is young, cellular, and vascular. At that time the injured nerve was beginning its growth also. It was in granulation tissue, with many branching, irregularly coursing blood-vessels. These vessels directed its way, the new tendrils following the capillaries, there being no stronger force, such as the chemotropic influence of an opposite nerve stump, to attract it. Finally it may reach the old gap, but conditions now (at the end of weeks or months) are very different. Instead of a loose, vascular, cellular tissue, there is firm, dense, connective tissue. The nerve may perchance follow a vessel into this, and send a few young tendrils into the scar. The chances are that the wild, turning, twisting, spiral course it had already followed, for the most part under the influence of the capillary blood-vessels, will now be exaggerated. A bulb results.

It is not due to lack of ability to grow that the nerve bulb forms. It is rather due to its excessive hardihood. It coils when it cannot pass the block. Conditions made artificially by the surgeon at this stage are not to be compared with those existing at the beginning, when the granulation tissue was responsible for the tortuous path of the nerve, at the same time forming the fibrous scar. At the operation, months later, the young prolific nerves are, at the point of clean cut, ready to join their mates across the way. Any blood-vessels that form take the same direction.

In spite of all that must be said about the harm done by connective tissue in nerve work, this fact must not be overlooked, that nerves grow in scar tissue

(*Figs.* 434, 435). I have found them in 90 per cent of the so-called 'chéloïdes nerveuses.' True, they are not seen as a rule in great numbers, but they get there. At times I have found them in bundles, and more prolific than in the proximal end (*Figs.* 412, 427).

This scar tissue was sclerotic in only one of the cases described (Weir Mitchell refers to sclerosis of the connective tissue occurring rarely). It is usually wavy, vascular, cellular, connective tissue. Much of the density of the connective tissue (adhesions) about nerves is due to the great numbers of nerve tendrils mixed with the connective tissue. That massive nerve growth is firm has been demonstrated in the nerve bulbs.

The microscopic appearance of such masses of tissue is shown in *Figs.* 412, 422, 427, 433. Another section, a longitudinal one, through such a mass showed the fibrous part on the proximal side of the excised nerve, the *distal* portion being typical nerve callus.

Of course the severe trauma and infection are the usual basis for the scar formation. Tinel adds that "the hæmorrhagic infiltration determines 'à la longue' the fibrous infiltration of the nerve."

Adhesions.—The scar seen in adhesions is usually cellular, hæmorrhagic, vascular, and pigmented The nuclei are not compressed into flat spindles as in dense scar tissue, but are usually larger and vesicular. This may be said of most of the connective tissue that I have examined from about nerves.

Of the adhesions, 82 per cent contain nerves. These are usually seen as tendrils 1 to 3 μ in size, discrete in the connective tissue; but it is not uncommon to find bundles of nerves in the adhesions. Most frequently they occur in the form of small masses of interlacing fasciculi (nerve callus).

Tender Skin Scars.—Weir Mitchell examined painful skin scars "without being able to find the microscopic state of their nerve fibres." The neurokeratin stain demonstrates its value in the readiness with which these compressed nerves take the colour. I have invariably found both coned and varicose fibres in tender skin scars; and I have been just as unsuccessful in staining them in painless scars. The nerve bundles are sometimes seen also in the subcutaneous tissues.

Neuritis.—We have many specimens with small round cells infiltrating the endoneurium and perineurium. At times these cells are seen massed about blood-vessels. Foreign materials such as khaki, bone, hair, or gravel, may be surrounded by them. There is an admixture of epithelioid cells in these cases, and sometimes of plasma cells—evidence of chronic neuritis. If foreign bodies be present, giant cells surround them. As blood pigment is such a common finding in our material, we very often see it incorporated in phagocytes. Weir Mitchell writes that there is an extension of productive inflammation a great distance along the nerve. Tinel thinks that the hæmorrhagic exudate has a great deal to do with producing the neuritis type of trauma.

A type of chronic neuritis is seen in many of the nerve trunks we have examined; here small fasciculi of new tendrils follow the newly formed vessels in the young connective tissue. These fasciculi contain two to ten fibres, and interlace among the large nerves so as to form a network. This growth of young nerves, so commonly seen in the proximal segment, may be analogous to Kennedy's findings. He states that the nerve trunks in old amputated

limbs always contain an abnormal number of small nerve fibres in bundles. He takes them to be like the 'immature' fibres in the peripheral segment of a divided nerve.

Guinea-pig Transplants.—Phillipeaux and Vulpian, desiring to prove that nerves grow autogenically, transplanted normal lingual, hypoglossal median, and sciatic nerves beneath the skin of young animals. At the end of six months they found a new growth of young fibres, following degeneration of the original implant. Bethe and Kennedy likewise grew implanted nerves in animals. Ingebrigtsen was able to demonstrate the growth of nerves in Ringer solution after having left them *in loco* for five days following section.

The material I used for inoculation was excised from war injuries, and growth occurred at once in every instance. Even in the infected case, a prompt growth occurred. In most cases the growth was more mature in appearance than the control piece, for alongside the young branching varicose tendrils were found fasciculi and bundles of full-grown fibres.

We have an unusually readily growing material in nerves from war injuries, whether from proximal or distal end, completely or incompletely divided. Even where the control (*Figs.* 436, 437, 438, 439, 440, 441, 442) demonstrates few very fine tendrils, and these scattered throughout connective tissue, the resulting growth is in the shape of fasciculi and branching varicose tendrils of both young and fully-grown fibres. The fibres in the controls in no case are as well grown or as easily demonstrated as those of the transplant.

No growth can be demonstrated in the centre of the inoculated mass; it is seen at its periphery, and in the fat and granulations, skin, or muscle round about. Growth is usually seen along blood-vessels or in thrombosed veins. It is visible in the subcutaneous fat or connective tissue of the skin, and alongside the glands. Fasciculi are demonstrable crossing a space between granulations and skin. The conical formations and neurokeratin sheath of the axis-cylinders can be seen in our sections.

The normal varicose appearance of young actively growing nerves is proven beyond doubt. That nerves will grow under most unfavourable conditions was seen in a five-day growth, where the wounds were both open, and the guinea-pig died of infection. Some idea of the rate of growth may be obtained from these experiments. Skin controls made from the guinea-pig showed no nerves in the adjacent skin; but in sections from other guinea-pigs' skin I found a few bundles, but no young tendrils.

The neurokeratin stain is of value in determining the difference between a full grown and embryonal nerve. It demonstrates the nerve supply to the lymph gland and in the periglandular fat. Some of the fasciculi in the periglandular lymph sinuses and in the lymph spaces were possibly carried to the gland in the lymph stream and grew locally. They are seen with hair, degenerated muscle, and poorly-stained fragmenting pieces of nerve in some of the lymph spaces, and in periglandular fat among the vascular organizing connective tissue (*Fig.* 456). The nerves are seen as discrete young varicose tendrils branching about blood-vessels lining the lymph spaces. The adult fibres in these glands are medullated, they contain myelin globules, and stain with osmic acid (Schäfer says they are non-medullated).

The possibility of such a distant growth does not seem so remote when we note, in *Fig.* 446, a new growth of nerves in a piece of the original transplant which, carried from its original place of anchorage, grew at a point an inch away from its mate, which latter continued to grow independently near the scar. We might explain such a growth by the diapedesis or wandering of Schwann-sheath cells, as suggested by Kennedy, Kirk and Lewis, and Ingebrigtsen. Howell and Huber refer to the penetrating of scars by the protoplasmic masses of these neuroblastic cells—they could more readily find their way in the vital fluids of a guinea-pig.

In one guinea-pig we find nerves sending tendrils among the silk sutures used in closing the skin wound.

It is of more than ordinary significance that these transplants, taken from nerve callus and embryonal fibres growing in eight-months' scar tissue, should grow at once. Vulpian's implants from normal nerves degenerated before they began to grow—taking six months to get a start.

Nerve Stretching.—In order to determine what occurred to the nerves in war injuries where so much of the nerve was removed that stretching was necessary to get the ends together, I experimented on guinea-pigs' nerves, and include the result in this report.

One guinea-pig had its sciatic stretched, and seventeen days later examination demonstrated granulation tissue about the nerve. Blood pigment and phagocytes containing pigment granules were in and around the nerve. Varicose tendrils, 1 to 3 μ in size, were seen among the wider adult fibres, some of which were torn. There were many young varicose fibres in the granulation tissue surrounding the nerve.

S. Mayer has demonstrated that there is a continual degeneration and regeneration normally taking place in a nerve. We may, therefore, expect the neurilemma-sheath cells rapidly to repair damage done by stretching.

Weir Mitchell's experiments proved that a sciatic nerve continues to react to electrical stimuli until stretched three-quarters of an inch in three inches.

Langley quite recently writes: "New fibres can stand much strain. They may be used in a few weeks."

Bethe demonstrates that a stretched nerve unites as well as an unstretched one.

CONCLUSIONS.

There is a neurokeratin framework of the medullary sheath which envelops the axis cylinder as a sheath.

The carbol-fuchsin–osmic-acid–oil of cloves method is a specific stain for neurokeratin.

The Schmidt-Lantermann segments are normal physiological entities. Each segment is seen in adult nerves as a conical-shaped body attached by its base to the neurilemma sheath, and it envelops the axis cylinder for 10 to 20 μ. Extension and pressure of a nerve accentuates the appearance of the conical segments.

Adult and young nerves may be easily differentiated—the former showing conical segments, the latter appearing varicose and often taking a spiral

course. The young nerve is 1 to 3 μ in diameter, the adult measures 6 to 14 μ.

The so-called vacuoles are myelin globules surrounded by a fine neurokeratin film; they are seen in normal nerves of the human embryo and adult and in the guinea-pig.

Medullated nerve fibres occur normally in lymph glands of the guinea-pig.

War-injured nerves are ready to unite at both ends of the injury before the end of eight months. (The distal end has picked up some kind of central trophic influence in 86 per cent of our cases.)

The hardness of a nerve does not mean that it is fibrous—the nerve bulbs are very hard—three-fourths of each usually consists of young nerve fibres. These fibres contain axis cylinders, demonstrated by Bielschowsky's stain. They grow when transplanted into guinea-pigs, even quicker than the fibres of normal nerves.

The proximal and distal ends, the middle zone, and the adhesions contained nerves in the following proportions: proximal, 100 per cent; distal 86 per cent; middle, 90 per cent; adhesions, 82 per cent.

By the time the scar between the severed nerve ends has formed, the bulbous ends have already reached maturity.

The nerves in nerve bulbs are turned back on themselves. They multiply indefinitely. We have seen them actively forming seven years after operation. Some die as others form. They cause pain apparently by their excessive proliferation against resistance. Young nerves are found in most of the nerve trunks several centimetres proximal to the seat of injury (the point of resection). They are not confined to the line of the nerve. They course among the adult fibres singly and in fasciculi, often resembling nerve callus.

The grayish-pink pulpy (gelatinous) appearance of the cross-section of a nerve is due to vascular, protoplasmic, much nucleated material in the small nerve bundles—it means nerve regeneration. The denser grayish-white sections dotted with gray or grayish-pink points signify regeneration of young nerves; they have reached a fuller development than in the more pulpy (succulent) areas. All of this material grows rapidly in the guinea-pig transplant.

Constricting scar is particularly damaging when circular (around the nerve).

Nerves pulled aside by bone callus or adhesions always contain well-developed fibres.

Adhesions, middle-zone scar, and surrounding injured nerves are means of keeping the distal segment alive.

Some of the quickest good clinical results occurred in cases where only young nerves were found in the pathological material.

The old degenerated nerve fibres form the best conducting paths for the growth of young tendrils.

There is a strong attractive force (neurotropismus) exerted by one nerve on another growing nerve.

Nerves grow best from the proximal end.

Nerves grow well in granulation tissue. Blood-vessels act as a scaffolding along which and within which nerves grow; in the early stages of nerve injury they tend to misguide a nerve from a straight path.

Nerves grow well in fascia lata, and in fact better than in muscle; but Cargile membrane is impervious to them.

Nerve tendrils grow about foreign material, such as khaki, hair, and sutures.

The neurilemma-sheath cells proliferate greatly in and around the old nerve fibres and at a distance, giving rise to new fibres. The sheath cells find their way into neighbouring and distant tissues. The nuclei are seen in great numbers before the young fibres sprout, and disappear as these tendrils appear.

Nerves which reach the scar tend to penetrate it.

The connective-tissue formation between nerve ends, around them, and within them, is usually wavy and vascular, often cellular, scarcely ever sclerotic.

Nerves are invariably seen in painful scars.

The subcutaneous implants into guinea-pigs of pieces from the proximal and distal ends and from the bulbs on the sides and ends of injured nerves, grow at once. There is no primary degeneration such as occurs when normal adult nerves are transplanted.

The implanted nerves grow at various points separated from the original seat of inoculation, suggesting a metastasis by cells of the neurilemma sheath.

The transplanted nerve grows in lymph glands when carried to them in the lymph stream as neurilemma-sheath cells.

Transplanted nerves grow even when infected.

The transplant growth in granulation tissue finds its way to distant nerves.

A stretched nerve shows active new growth of young tendrils.

I wish to thank Colonel Sir Robert Jones for giving me the opportunity to do this work. To Professor Ernest Glynn I am much indebted for suggestions, and for his kindness in giving me every facility at the Thomson Yates Pathological Laboratory to carry on these investigations.

The execution of the photomicrographs is the war contribution of Mr. R. Shepherd, for which we are most grateful.

[*Illustrations of this article will be found on pp.* 549–557.]

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HISTOLOGICAL APPEARANCES.

FIG. 405. (× 480.)

FIG. 405.—Nerve from an amputation stump, stretched at time of excision. Nerve entering stump bulb. Invaginated (intussuscepted) appearance at location of Schmidt's incisures. Axis cylinder sheath can be seen.

FIG. 406.—Stretched nerve from stump. Cones and globules of myelin outlined by neurokeratin framework. Axis cylinder sheath and attachment of base of cones at neurilemma sheath seen as circles. The light area between the inner circle (axis cylinder sheath) and outer circle (base of cone attached to the sheath of Schwann) is the medullary sheath.

FIG. 406. (× 480.)

FIG. 407. (× 480.)

FIG. 407.—Same as 406, cut less obliquely. Regular arrangement of cones 30 μ long. Axis cylinder sheath demonstrated. Myelin globules ('vacuoles') seen enveloped by neurokeratin framework.

FIG. 408.—Side bulb on ulnar nerve. Ulnar was grafted with rabbit's nerve 7 years ago. Cones and globules. Several 3 μ nerves among adult (12 μ) nerves faintly outlined. The globules of myelin are seen outlined by neurokeratin in the fibres at the margin of the photo; these were cut near the sheath of the ulnar.

FIG. 408. (× 480.)

FIG. 409. (× 480.)

FIG. 409.—Same as 408. Globules of myelin not taking the stain. Neurokeratin deeply stained.

FIG. 410.—Sciatic nerve regenerating: proximal end, 2 months; cut 25 μ thick. Numerous young tendrils in swollen protoplasmic material ('axial strands') in old fibres. A few nuclei faintly outlined seen in surrounding cellular connective tissue. (Stained by Van Gieson, the circles from which these tendrils project were seen to be full of nuclei in swollen protoplasm.)

FIG. 410. (× 480.)

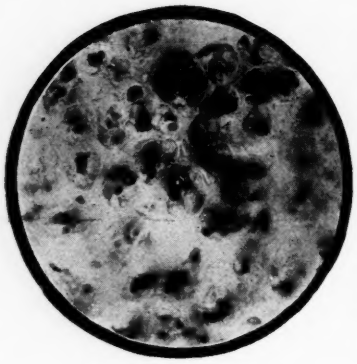


FIG. 411. (× 480.)

FIG. 411.—Same as 410, lower down the section. Some balls of degenerated myelin (stained black) alongside young nerves. A few faintly outlined nuclei. The smaller dark objects are nerves—they were stained mauve.

FIG. 412.—Section at middle of excised nerve. Young nerves (2 to 3μ) outlined in protoplasm of old fibres. Black border of fibre has a notched appearance, due to the closely aggregated young nerves. The very faint splotches throughout the section are nuclei; they do not take the mauve colour, so are photographed with difficulty.

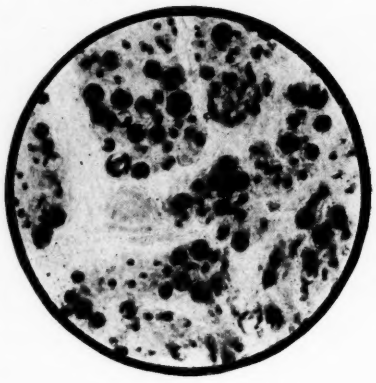


FIG. 412. (× 480.)

FIG. 413. (× 90.)

FIG. 413.—Numerous young varicose spiral fibres in old fibres of nerve bundle. Proximal end. Four months' growth. There are 5 to 10 new tendrils in each original nerve fibre.

FIG. 414.—New growth in old fibres and in thickened perineurium of distal segment of excised nerve. No adult fibres with cone formation were seen under higher magnification.

FIG. 414 (× 90.)

FIG. 415. (× 240.)

FIG. 415.—Many good adult nerves (7 to 10μ) with cones in old trunk of distal end of completely divided nerve. After 6 months. A few 3μ nerves and some non-staining old fibres and connective tissue are seen.

FIG. 416.—Tendrils and adult nerves in old bundle in peripheral segment of excised nerve.

FIG. 416. (× 240.)

FIG. 417. (× 480.)

FIG. 417.—Axis cylinders stained by Bielschowsky's method in peripheral segment of excised nerve.

FIG. 418.—Foreign body with a branching nerve tendril close to it. Other tendrils, near by, could not be brought into the same focus with the one photographed.

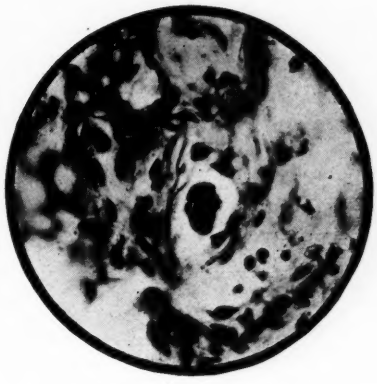


FIG. 418. (× 480.)

FIG. 419. (× 240.)

FIG. 419.—Bundle of adult and young fibres in lumen of thrombosed vessel. The nuclei in the vessel walls are faintly outlined.

FIG. 420.—Same as *Fig.* 419. Young varicose fibres (2 to 4 μ) growing in walls of vein. They are spiral in form and run in various directions.

FIG. 420. (× 240.)

FIG. 421. (× 480.)

FIG. 421.—Young nerve fibres in vein. Section made at point of branching of vein. There is a fasciculus in the centre. Several varicose tendrils are seen in the branch.

FIG. 422.—Cross-section of proximal end of excised nerve. Endoneurium increased. Higher magnification demonstrates young tendrils in the old fibres. Cell increase present. Macroscopically it was pinkish-gray, gelatinous, and divided into lobules (funiculi).

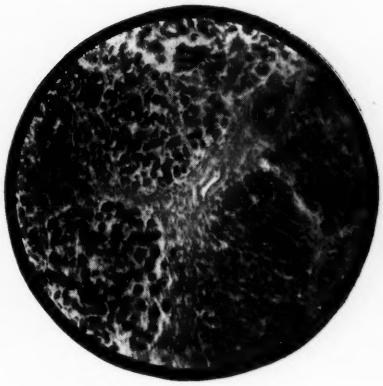


FIG. 422. (× 90.)

FIG. 423. (× 90.)

FIG. 423.—Young nerves in distal segment of excised nerve, intertwining as in nerve callus. Some tendrils discrete in the thickened connective tissue. Fasciculi are seen cut longitudinally and transversely.

FIG. 424. — Fasciculi of young fibres in vascular connective tissue alongside a nerve bundle in adhesions. The black mass is the bundle—individual nerves may be traced.

FIG. 424. (× 90.)

FIG. 425. (× 90.)

FIG. 425.—Bundles of full-grown coned fibres in proximal end. Much loose connective tissue, infiltrated with blood, surrounds the bundles.

FIG. 426.—Proximal end. Many good fully-formed fibres in old degenerated bundle (2¼ years). Connective tissue has taken the place of many fibres, and is increased in the endo- and perineurium. (Magnification × 400 demonstrates cones in some of the fibres.)

FIG. 426. (× 90.)

FIG. 427. (× 90.)

FIG. 427.—Excised nerve; 6 cm. removed; section is from the firm fibrous portion near the middle. Fasciculi of good adult fibres. The fasciculi are more definitely circumscribed than usual.

FIG. 428.—Very much like *Fig.* 427. Interlacing fasciculi like those seen in nerve callus. The fibres are all young. This kind of tissue is very common in the proximal segment.

FIG. 428.

FIG. 429. (× 90.)

FIG. 429.—Interlacing fasciculi of young nerves in loose hæmorrhagic connective tissue. Taken from adhesions around the nerve.

FIG. 430. — Nerve callus from bulb of posterior tibial bound in scar tissue to bone. Very little connective tissue among fasciculi. These measure 10 to 30 μ and contain tendrils of 1 to 3 μ. Van Gieson's stain shows numerous nuclei—elongated and oval-shaped.

FIG. 430. (× 90.)

FIG. 431. (× 90.)

FIG. 431.— From adhesions to the nerve. Nerve callus makes up the mass of the adhesions. Interlacing fasciculi of young nerves. Little connective tissue.

FIG. 432.—Nerve callus of bulbous end of nerve. Young varicose tendrils (1 to 3 μ) in fasciculi. Connective tissue unstained. Nuclei faintly outlined as blurred masses alongside the tendrils.

FIG. 432. (× 240.)

FIG. 433. (× 90.)

FIG. 433. — Nerve callus from bulb. Interlacing fasciculi, more nerve than connective tissue.

FIG. 434.—Painful skin scar at end of stump. Coiled fibre in connective tissue, following a blood-vessel. Only one fibre in this fasciculus could be focussed properly in taking the photograph. Specimen gave positive result with Bielschowsky's axis cylinder stain.

FIG. 434. (× 480.)

FIG. 435. (× 240.)

FIG. 435. — Painful skin scar. A fasciculus of newly-formed nerves in dense fibrous tissue, blood-vessel alongside. Coned (8 μ) and varicose (3 μ) fibres seen in the same fasciculus.

FIG. 436.—Distal end of excised internal cutaneous nerve. A guinea-pig was inoculated with a piece from this (cf. *Figs.* 443, 444, 445). A few young varicose tendrils in vascular cellular connective tissue. (Many elongated blunt neurilemma sheath nuclei were seen in this section.)

FIG. 436. (× 480.)

FIG. 437. (× 90.)

FIG. 437.—Proximal end of excised internal cutaneous nerve. A guinea-pig was inoculated with a piece from this 'control' (cf. *Figs.* 446, 447). A few good adult coned fibres among proliferating nuclei of the neurilemma sheath. (This is frequently mistaken for connective tissue.)

FIG. 438.—Distal end of ulnar nerve. A piece from this was implanted into a guinea-pig (cf. *Figs.* 448, 449). Discrete young varicose tendrils (black) in loose cellular connective tissue.

FIG. 438. (× 480.)

FIG. 439. (× 480.)

FIG. 439.—Distal end of ulnar from which a piece was transplanted into a guinea-pig (cf. *Figs.* 450, 451, 452, 453). Varicose young fibres (3 μ) in connective tissue.

FIG. 440.—Distal end of ulnar. Implant from this was placed in subcutaneous tissue of guinea-pig (cf. *Figs.* 454, 455, 456, 457). A few discrete young varicose tendrils in cellular connective tissue. (Several fibres are in the field, but only one at a time could be well focussed.)

FIG. 440. (× 480.)

FIG. 441. (× 480.)

FIG. 441.—Nerve from 3½-months' fœtus, showing cones and globules.

FIG. 442.—From second bulb of proximal segment of ulnar nerve. A piece was implanted into a guinea-pig (cf. *Fig.* 458). There are a number of tendrils (1 to 2 μ) in a bundle, running parallel in dense connective tissue. There was great round-cell infiltration and dense connective-tissue formation, and little evidence of new nerve formation elsewhere.

FIG. 442. (× 90.)

FIG. 443. (× 240.)

FIG. 443.—Eight-day growth in guinea-pig transplant. Fasciculus of young and full-grown fibres in granulation tissue in the subcutaneous fat. (*Fig.* 436 represents the control piece.)

FIG. 444.—Eight-day growth in guinea-pig transplant. Discrete young fibres in subcutaneous connective tissue. Nerve appears black, nuclei blurred.

FIG. 444. (× 480.)

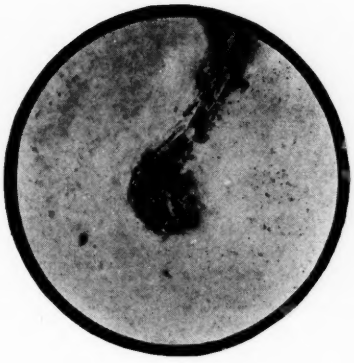


FIG. 445. (× 240.)

FIG. 445.—Eight-day growth in guinea-pig transplant. Degenerated fasciculus in granulations. Cones broken. Black fragments of myelin displaced.

FIG. 446.—Guinea-pig transplant (8 days). Cellular granulation tissue. The piece was separated by an inch from growth at scar. Both varicose (young) and coned (full-grown) fibres are seen. (*Fig.* 437 shows the control piece from which this grew.

FIG. 446. (× 480.)

FIG. 447. (× 480.)

FIG. 447.—Growth in guinea-pig (8 days). Fasciculus of young fibres in vascular granulations in subcutaneous connective tissue. Nuclei proliferating and seen in close relation to nerve tendrils.

FIG. 448.—Growth in guinea-pig (13 days). Fasciculus in granulations in subcutaneous fat. Young and full-grown nerve fibres. Nerve was cut as it changed its direction.

FIG. 448. (× 240.)

FIG. 449. (× 480.)

FIG. 449.—Growth in guinea-pig (13 days). Fasciculi from which varicose branching tendrils are spreading in the guinea-pig's muscle. Note the bulbous ends of the growing young nerves. (The spiral form makes it impossible to show the entire length of the tendril in the picture.) Nerves appear black.

FIG. 450.—Growth in guinea-pig (35 days). Single tendrils in granulations in subcutaneous tissue, appearing varicose and spiral.

FIG. 450. (× 480.)

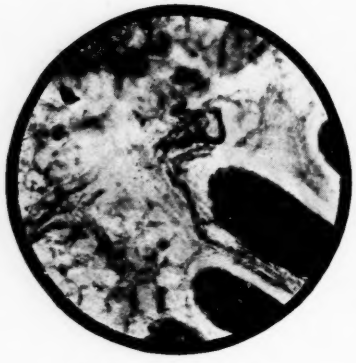


FIG. 451. (× 90.)

FIG. 451.—Growth in guinea-pig (35 days). Young varicose fibres in spiral form growing about hair sacs.

FIG. 452.—Growth in guinea-pig (35 days). Transplant made in thigh. Young spiral tendrils following a blood-vessel in granulation tissue in lymph sinus of lymph gland in groin. Some may be faintly seen out of focus. ¡Lymph follicles alongside.

FIG. 452. (× 90.)

FIG. 453. (× 90.)

FIG. 453.—Growth in guinea-pig transplant (35 days). Young spirals in granulations in subcutaneous fat. Several varicose tendrils in each fasciculus. They follow faintly-outlined blood-vessels.

FIG. 454.—Transplant in guinea-pig (18 days). Fasciculus in muscle. Full-grown (8 μ) fibres.

FIG. 454. (× 90.)

FIG. 455. (× 480.)

FIG. 455.—Growth in guinea-pig transplant (18 days). Fasciculus of full-grown fibres (myelin globules noted) in subcutaneous tissue. Cones and axis cylinder sheath faintly outlined.

FIG. 456.—Growth in guinea-pig transplant (38 days). Lymph-gland sinus, containing granulations, nerve fasciculi, and discrete tendrils. Fasciculi are densely stained (black). Young spiral tendrils in narrow fasciculus at edge of granulations.

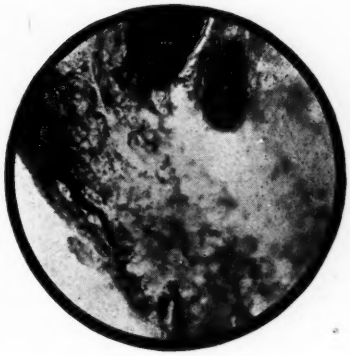


FIG. 456. (× 90.)

FIG. 457. (× 240.)

FIG. 457.—Growth in guinea-pig (38 days). Spirals of young varicose tendrils in granulations among muscle fibres.

FIG. 458.—Growth in guinea-pig transplant (5 days). Fasciculus in granulations about piece near groin separated from original seat of inoculation. Fasciculus in granulation tissue alongside degenerating inoculated mass.

FIG. 458

A STUDY OF A SERIES OF WOUNDS INVOLVING THE BRAIN AND ITS ENVELOPING STRUCTURES.

By HARVEY CUSHING.

Director U.S. Army Base Hospital, British Expeditionary Force.

SUMMARY OF CONTENTS.

Foreword: Material and Source.

Classification of Wounds of the Head: The following subdivisions adopted:—

Group I.—Scalp wounds: with or without cerebral contusion.
„ *II.*—Wounds with local fractures but with intact dura: with or without cerebral injury.
„ *III.*—Wounds with depressed bone-fragments puncturing dura, and cerebral contusion.
„ *IV.*—Wounds with detached and indriven bone-fragments: brain usually extruding.
„ *V.*—Penetrating wounds with projectile lodged; brain usually extruding.
„ *VI.*—Wounds with bone-fragments or projectile opening ventricle: brain usually extruding.
„ *VII.*—Wounds involving (*a*) orbito-nasal, (*b*) auro-petrosal region: brain exposed: meninges opened.
„ *VIII.*—Perforating wounds: cerebral injury severe.
„ *IX.*—Bursting fractures: extensive cerebral contusion.

The Unoperated Cases.

The Operative Procedure.

The Complications and End-results.

FOREWORD.

When novel surgical experiences, no matter how numerous, are crowded into the period of a few weeks, it is unsafe to draw too many deductions therefrom. The past three years have shown how often favourable opinions which were not based on the study of end-results have had to be retracted—how often unfavourable opinions, based on improperly conducted operations, have had to give way to the results of those better planned. One needs but recall the story of many of the antiseptics, of abdominal operations, of experiences with wounds of the thorax and joints, of primary and secondary suture of wounds. Hence, what may be said in these pages is said with all reservation and with full admission of a brief apprenticeship.

After these three years there is possibly less unanimity of opinion as regards the principles of treatment of cranio-cerebral injuries than of any other type of wounds. Reasons are not far to seek. Anything classified as neurological is looked upon by many of us as baffling and difficult, and a feeling prevails that the ultimate functional results after recovery from serious cranial injuries are, to say the least, forlorn. Few medical officers had received training in the surgery of the central nervous system before the

war; no organized instruction has been given in the subject since; and the tools provided for the work have been inadequate and antiquated. Furthermore, diverse, and at times confusing, opinions have been expressed regarding the treatment of these conditions, without accompanying mortality figures and illustrative clinical records to serve for others as a basis for comparison. For without definite statistics, accompanied by case-histories, the surgeon cannot tell what have been the surgical results in the past of methods different from his own; without them he cannot tell whether his own percentage of recoveries is improving as time goes on.

With the object therefore of placing on record the account of a consecutive series of surgically-treated cases, with results both good and bad, this paper has been put together; and such opinions as are expressed are given with full appreciation of the sentiment in the opening paragraph.

Material.—During the three months from July 23 to Oct. 31, 1917, a series of 250 examples of injury to the head came under the care of a 'surgical team,' of which the writer was a member, at a casualty clearing station in which all so-called head cases for a given army front were congregated.

As recorded elsewhere,* 219 of these cases, which were in large part referred to us or selected by us as being cases of major gravity, were operated upon, disclosing wounds of the following types. There were 22 cases with scalp wounds (10·1 per cent), 54 with wounds involving cranium as well as scalp, but with intact dura (24·6 per cent), 133 with wounds with dural penetration (60·7 per cent), and 10 (4·5 per cent) massive or bursting fractures with serious intercranial complications, though usually with intact scalp and dura. The 31 additional cases comprised 20 whose condition on admission precluded operation, and 11 whose injuries were allowed to pursue their course without actual operation.

In the above report on the 219 cases, attention was called to a method of treating penetrating wounds, its essential features being the removal *en bloc* of the area of bony involvement, the withdrawal by suction through a soft catheter of the devitalized cerebral tissue lining the track, without enlargement of the dural opening, and the extraction of bone fragments with the least possible increase in the trauma already produced. A progressive improvement in the percentage of recoveries was attributed in large part to the adoption of these methods, for the mortality of the 133 cases with dural penetration had been lowered from 54·5 per cent for the first 44, to 40·9 per cent for the second 44, and to 28·8 per cent for the third 45 cases.

These figures, it should be pointed out, represent the combined results of a single team, the junior members of which were occasionally changed, and though all of us operated from time to time, the writer is responsible for the majority of the cases. No cases have been eliminated from the series for any cause, even when death has been obviously due to some complicating condition apart from the injury to the head.

At the outset we had no settled programme, except to limit ourselves, so far as circumstances permitted, to the cases with dural penetration, the post-operative mortality of which, from hearsay, we were led to believe was

* "Notes on Penetrating Wounds of the Brain," *Brit. Med. Jour.* 1918, Feb. 23.

something over 50 per cent. There were no prescribed rules of procedure, aside from the regulation that after operation cases should be retained for ten days, as transportation was supposed to favour the post-operative complications so frequently seen. Unoperated cases, on the other hand, with the exception of those with a rapid pulse, could if necessary be forwarded to the base; indeed, there was some contention that all cases should be sent to base hospitals for their operation, as there was no harm and possibly some advantage in the delay.

Our early operations, under a general anæsthetic, with flap exposures and imperfect cleansing of the track, did very badly, and the mortality, usually due to infection, ranged between 50 and 60 per cent. The usual line of treatment and sequel may be told by a case report.

Case 1.—Rfm. J. Y. (Serial No. 7). **Left parietal penetrating wound. Incomplete operation: bone fragments and small projectile retained. Abscess; fungus cerebri. Death: encephalitis, 12th day.**

Admission to C.C.S. July 29, 1917, 9 a.m.—Wounded about eight hours previously; wearing helmet. Stunned, but no loss of consciousness. Headache.

General Condition.—Good; fully conscious; warm; pulse 96.

Wounds.—Two small scalp wounds of left occiput; a small penetrating wound just below left parietal eminence. *X* rays show small fracture of left parietal, with metal fragment 10 cm. from plate near mid-plane of skull.

Neurological Findings.—Paralysis and spasticity of right arm and leg; weakness of right face. Also lowered sensory perception to pain. Slight paraphasia. Deep reflexes exaggerated in right arm and leg, without clonus; no plantar response. Possibly a right homonymous (upper quadrant) hemianopsia.

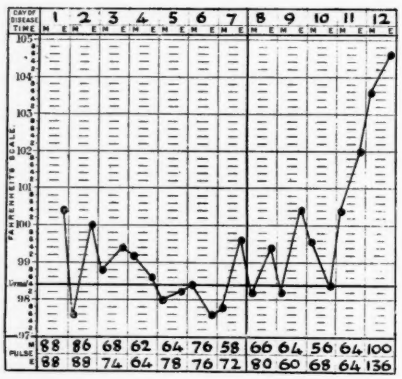


FIG. 459.—*Case* 1. Showing temperature rise after ten-day interval.

Operation, 10 a.m. (after 9 hours).—Ether. Flap reflected, with excision of scalp wound; enlargement by rongeurs of small opening in skull, disclosing a cerebral protrusion; circular resection, with enlargement of dural opening; removal by palpation and irrigation of a few superficial bone fragments from track in brain. Closure with lateral rubber-tissue wick drains. Multiple scalp wounds of occiput repaired. A rapidly conducted procedure.

Post-operative Course.—Incontinent, restless, and somewhat irrational for two days; required morphia. Superficial infection of wound, which was opened and Carrelized. Subsequently, general condition improved, though the neurological findings were unaltered. Slight rise in temperature on seventh day; some focal seizures in face. Small fungus cerebri, with discharge of two bone fragments and some disorganized brain tissue. On ninth day further discharge of bone fragments. Slowing of pulse. On eleventh and twelfth days rise of temperature to 105° (*Fig.* 459), with stupor. Death, Aug. 9, 11 p.m.

Autopsy.—Brain shows no evidences of meningitis. A fungus the size of a pigeon's egg overlies the left angular gyrus. The track of the projectile is surrounded by softened and septic brain tissue containing spicules of bone. It passes upward and slightly forward through the parietal lobe, internal capsule, and falx, and enters the right hemisphere, where lies a minute shell-fragment (*Fig* 460) surrounded by an abscess 3 cm. in diameter unconnected with the very septic track. The 0·35-grm. missile shows a burnished surface, evidently from helmet perforation.

This, in short, was a type of case with sequence all too common—an incomplete removal of infected bone fragments, resulting in a septic track, a spreading encephalitis, a broken-down wound with fungus, and death without meningitis. Meanwhile the small foreign body was making its own separate nest of trouble in the opposite hemisphere. The terminal upset, with rise in temperature on the eleventh and twelfth days, would naturally have been attributed to his transportation had he been evacuated the day before.

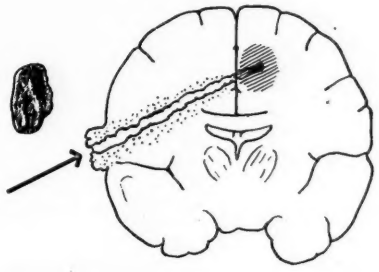


FIG. 460.—*Case* 1. Projectile (natural size), and course through brain.

The repetition of a few experiences of this kind led in time to a complete change in technique, after the manner described elsewhere,* with painstaking toilette of the track carried out without haste under a local anæsthetic.

CLASSIFICATION OF HEAD INJURIES.

For many people the term gunshot wound of the head brings up a picture of the cranial injury alone. It is the fractured skull which is exhibited in our museums, not the damaged brain. The various forms of fracture are thus familiar to all, and the teachings of operative surgery explain the use of the trephine and the manner of dealing with the fracture, scant attention being paid to the neurological lesion underneath.

Fractures of the skull have been most variously classified—according to their anatomical situation (frontal, temporal, basal, etc.), according to the character of the bony lesion (fissured, depressed, penetrating, etc.), according to the mechanism of their production (by bending, bursting, etc.). Gunshot wounds are usually placed in a separate category, which again has been made to undergo further subdivisions according to the nature of the projectile, its size or course, its lodgement or otherwise, the region of impact, the extent of radiation of the fissures, and many other qualities.

But, to the victim of the injury, what has happened to the skull is of far less moment than what has happened to the brain, and this has been given less study. Indeed, since the time of Hippocrates we have been warned against carrying our investigations beneath the dura. This, however, we are often compelled to do, and in so many cases has the membrane been opened for us by the missile, that a subdivision of projectile wounds of the head into those with and those without dural penetration has become a fairly common one. We thus have already had forced upon us some recognition of the intracranial injury in our efforts suitably to classify wounds of the head.

In the present paper the attempt will be made to carry the matter a little further, and to grade the cases in accordance with the seriousness of the condition so far as the cranial contents are concerned. The gradations

* *Brit. Med. Jour.* 1918, Feb. 23.

are tentative, and have been made as comprehensive and as few in number as possible; also with the least possible dislocation of our old formulas regarding the cranial injury. The scale is one of ascending severity, and as will be seen, the surgical mortality for each successive group, with a single exception, is higher than the one before. There are doubtless imperfections in the scheme, and other subdivisions may be better, but it is thrown out merely as a temporary working basis on which cases may be recorded for purposes of comparison without too great elaboration.

HEAD INJURIES GRADED ACCORDING TO THEIR SEVERITY.

With mortality figures for each group under the condition recorded.

Grade I.—Wounds of the Scalp, with Intact Cranium and Dura.

Occasional underlying cerebral contusion. 22 cases: 1 death (4·5 %).

Grade II.—Wounds Producing Local Fractures of Variable Types, with the Dura Intact.

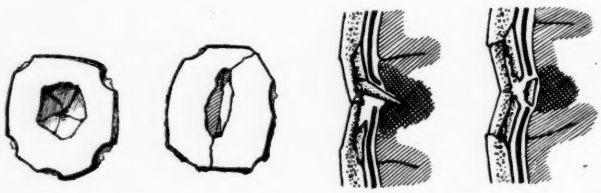
Type A. — Without depression of external table.

Type B.—With depression of external table.

Local contusions of brain or extradural extravasation fairly common.

54 cases: 5 deaths (9·2 %).

Grade III.—Local Depressed Fractures of Various Types, with the Dura Punctured.



Local contusions inevitable, usually with positive neurological signs; cerebral extrusion uncommon.

18 cases: 2 deaths (11·8 %).

Grade IV.—Wounds, Usually of Gutter Type, with Detached Bone Fragments Driven into Brain.

Local contusion severe, and extrusion of brain almost inevitable. Fungus cerebri, encephalitis, etc., common sequels.

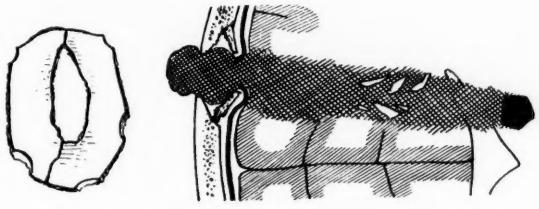
25 cases: 6 deaths (24 %).

Grade V.—Wounds of Penetrating Type, with Lodgement both of Projectile and Bone Fragments.

Brain often extruding: contusion along track. Symptoms depend on size and course of missile. Common sequels: early compression, late abscess.

41 cases: 15 deaths (36·6 %).

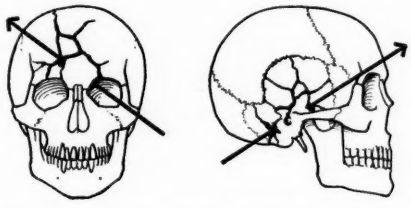
Grade VI.—Wounds with Ventricles Penetrated or Traversed (*A*) By Bone Fragments, (*B*) By Projectile.



Cerebral lesion as in *Grades IV* and *V*, with cerebrospinal fluid escape. Hæmorrhage into, or subsequent infection of ventricle common.

Type A.—
14 cases: 6 deaths (42·8 %).
Type B.—
16 cases: 16 deaths (100 %).

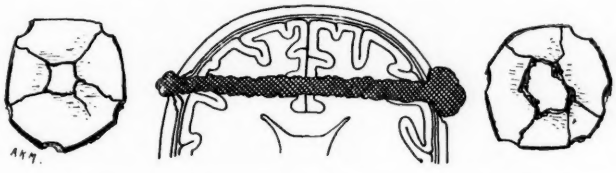
Grade VII.—Wounds of Cranio-cerebral Type Involving (*A*) Orbital-nasal, (*B*) Auro-petrosal Region.



Brain commonly exposed and extruding; radiating fractures; nasal or petrosal cavities opened; meningitis common.

15 cases: 11 deaths (73·3 %).

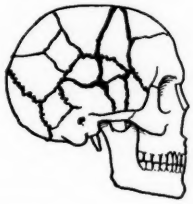
Grade VIII.—Wounds with Cranio-cerebral Perforation.



Extensive cranial and cerebral damage common. Death usually due to intracranial hæmorrhage and compression.

5 cases: 4 deaths (80 %).

Grade IX.—Cranio-cerebral Injuries with Massive Fracture of Skull.



Widespread cerebral contusion. Compression phenomena common.

10 cases: 5 deaths (50 %).

The present is no time to become deeply involved in new classifications. Hence, in the foregoing scheme, as few new elements as possible have been introduced, chiefly those relating to the important matter of intracranial infection—dural penetration, cerebral extrusion, ventricular penetration, and opened portals of infection through nose and inner ear. Other elements which greatly modify the wounded man's chance of recovery—the degree of shock and exposure, the establishment of infection before admission in cases lying out, the lapse of time between the injury and the operation, the multiplicity of cranial wounds, complicating conditions such as concomitant wounds elsewhere or gas poisoning—all these and many more modifying elements must be omitted, lest there be too great confusion.

Group I.—WOUNDS OF THE SCALP.

Of all superficial wounds, simple scalp wounds are possibly the most susceptible to primary closure, with early return of the patient to his duties. Hence the inclusion of scalp wounds in a discussion of wounds of the head might seem unnecessary, were it not for the tendency to underestimate them, and to forget that even among the walking wounded every scalp wound must be regarded as a potential penetrating lesion of the brain. For even with the help of radiography, it may be impossible to foretell what investigation will reveal in the way of an underlying lesion.

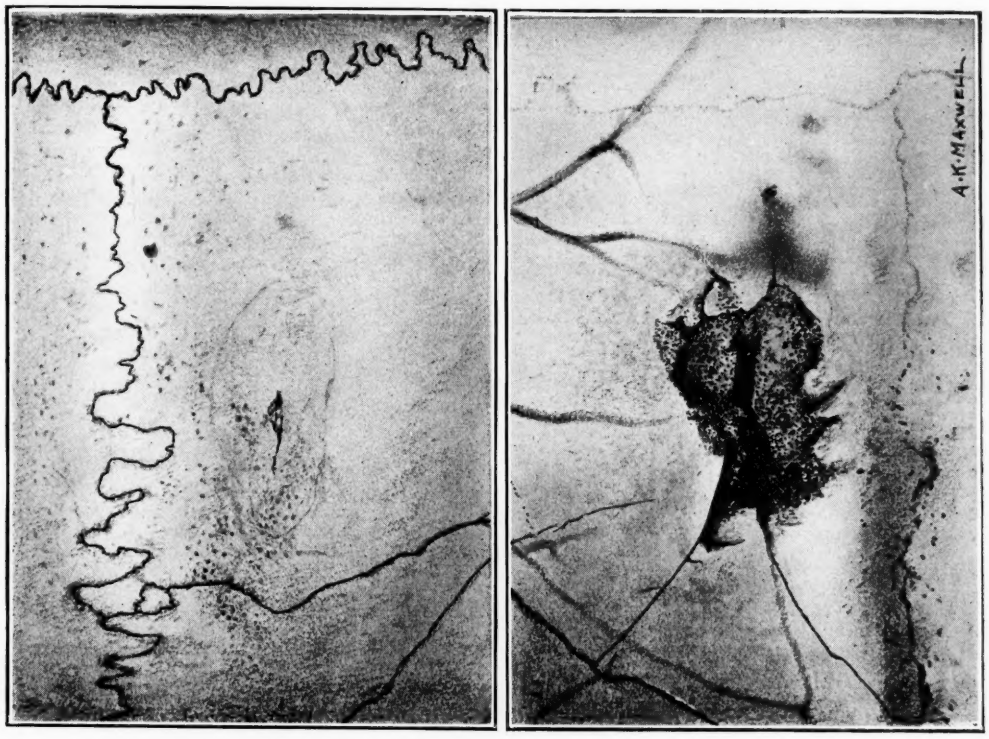
On the other hand, we may overestimate the scalp wound. In the series of 22 verified cases, there were 16 in which a cranial or cranio-cerebral injury was anticipated, either because of the patient's neurological symptoms, or because of the appearance of the external wound itself. For example, the field medical cards of three of the patients recorded the presence of a hernia cerebri, which on investigation proved to be merely a pulsating clot filling a superficial gutter-wound of the temporal muscle.

However, though many scalp wounds which appear serious prove to be trifling, more which appear trifling prove to be serious. Two cases of the series were prepared for operation owing to the presence of a large gutter wound of the scalp, with the expectation of finding a fracture; and not until the head had been shaved, was a small wound disclosed elsewhere which was actually a wound of penetration, the obvious wound proving on investigation to be limited to the scalp alone. All surgeons working in a forward area have had similar experiences. Even the *x* rays may not help greatly, for they often fail, on a lateral view, to disclose slightly depressed fractures; while on the other hand, irregularities of the skull, particularly those along the mid-vertex, may be mistaken for fractures.

Scalp wounds, in fact, cannot be glossed over in making a report on wounds of the head. The statistical study of all the cases with a diagnosis of gunshot wounds of the head or scalp, during a two weeks' period of military activity with a large number of wounded, disclosed the fact that 85 per cent of all the cases were immediately evacuated after a mere change of dressing —practically all of them walking cases, the wounds supposedly being scalp wounds. Many severe, even penetrating, wounds must have been included. It is of course a physical impossibility to examine neurologically, to submit

to an *x*-ray exposure, and to operate upon all cases in times of pressure; and whether the simple or the more severe wounds should be given operative attention at such a time is a matter for a military rather than a medical decision.

Twenty-two cases in the series were classified as scalp wounds on the basis of the operative findings, for the outer skull proved to be intact, and none of them were trephined. In 12 of them (54·5 per cent) there were complicating wounds elsewhere of greater or less severity. There was one fatality. This man's story may be cited at the outset, to illustrate the difficulties of any classification and the admitted imperfections of the one adopted.



FIGS. 461, 462.—*Case* 3.—Showing external table practically intact except for distant fissures; internal table with extensive defect (cf. *Fig.* 463).

Case 2.—Pte. T. L. (Serial No. 27). **Scalp wound, with fatality from contusion of hind-brain.**

Admitted Aug. 1, 1917, 9.30 p.m.—Unconscious. Pulse 90, irregular. Respiration shallow, rhythmic, gurgling. Multiple wounds of arm; scalp wound of mid-vertex. Exaggerated deep reflexes.

Aug. 2, 12.10 a.m.—Lumbar puncture: 50 c.c. very bloody cerebrospinal fluid. 2 a.m.—Operative repair of multiple wounds. Consciousness never regained. Cheyne-Stokes' respiration. Death in 48 hours.

Autopsy.—No cranial injury; outer aspect of brain normal, but there were clots and bloody fluid in the cerebellar fossa, and sections disclosed a small hæmorrhage in the cerebellar vermis.

The clinical diagnosis lay between fracture of the base and a parasinoidal contusion, neither of which was found. The case remains on record as one of "multiple wounds, including scalp." Trepanation in this case would have been unavailing, but it is quite probable that some of the other cases in this group should not only have been trephined, but should have had the dura opened as well, for eleven out of the number showed distinct evidence of moderate intracranial damage—a paraphasia, a partial or complete hemianopsia, or a slight motor or sensory monoplegia; and one or two severe scalp wounds of the vertex showed a certain degree of spasticity, indicating a bilateral contusion of the mesial portions of the hemispheres.

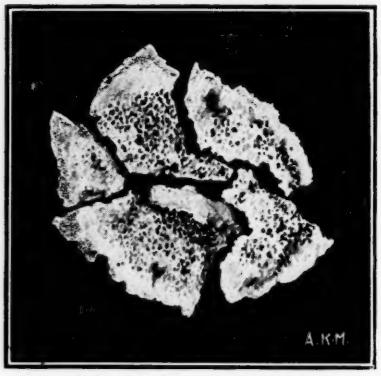


FIG. 463.—*Case* 3. The indriven fragments of inner table (natural size).

Among the cranial injuries of *Group II*, there are many examples of a slightly scored external table, and it is interesting to find that a larger proportion of these cases had intracranial symptoms than had those with a simple scalp wound. It is well known, however, that an intact external table may conceal an injury of the internal table, with serious cerebral contusions due to penetration of bone fragments. It is in cases of this kind that one's surgical judgement is put to the greatest test, for the temptation is great to follow a 'let alone' policy. Doubtless a temporizing policy is the wisest one if the scalp wound is seriously infected.

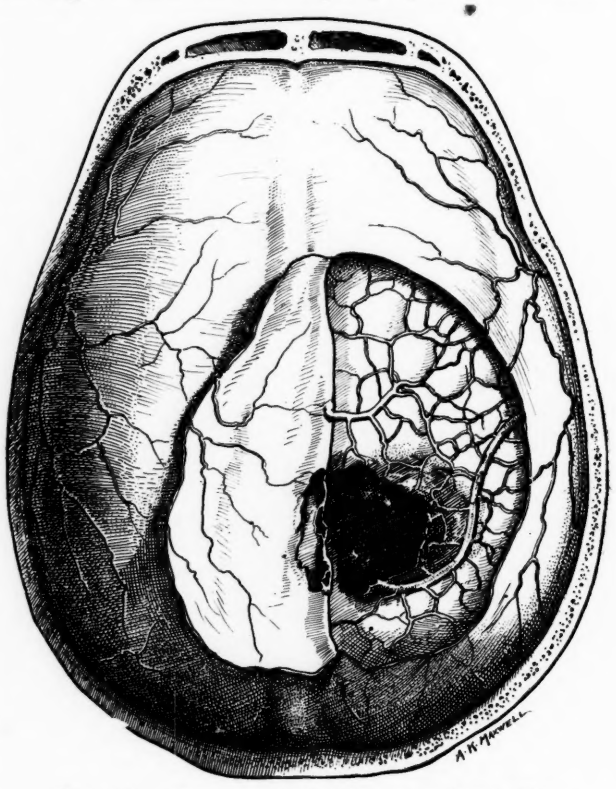


FIG. 464.—*Case* 3. From sketch at autopsy after removing calvarium.

The following case furnishes an example of a badly infected scalp wound with an apparently intact skull which probably would not have been trephined. The patient was on the pre-operation table after being shaved, and succumbed while awaiting his turn. The case, therefore, does not occur in the operation series.

Case 3.—Pte. J. G. **Spastic paraplegia. Very large gutter wound in mid-vertex. External table intact. Fragments of inner table driven through parasinoidal margin into hemisphere, with large area of disorganization. No operation. Death.**

Admission, Aug. 4, 1917, 2 p.m.—Wounded during the attack of July 31. Has been lying out since that time. Brought in by bearers to field ambulance this morning.

General Condition. — Profoundly unconscious; restless; cold. Pulse 140, irregular. Respiration 48, gurgling.

Wound.—A longitudinal gutter wound of vertex slightly to right of mid-line, 8 cm. in length. Margins very septic; stinking; containing maggots. In base of wound a dry, intact, denuded, external table was exposed. No *x*-ray examination.

Neurological Symptoms.—Apparent complete flaccid paralysis of left arm and leg. Patient moves right arm and leg, tearing at bandage with right hand. Deep reflexes exaggerated, with bilateral dorsal plantar response.

4 p.m.—Prepared for operation as a last resort. Died shortly after head was shaved.

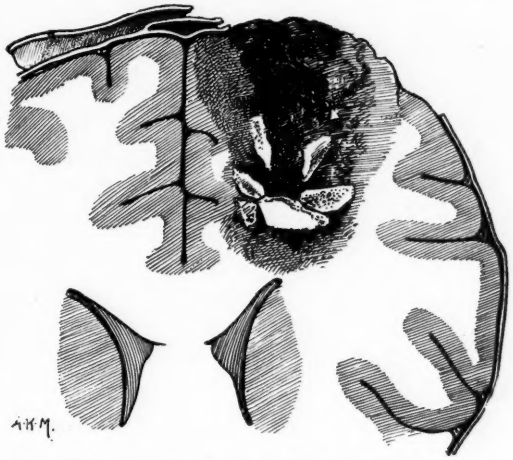


FIG. 465.—*Case* 3. Section through the contused area, showing position of bone fragments.

Autopsy.—The external surface of the calvarium is relatively intact (*Fig.* 461), with two or three fine linear radiating fissures extending across the parietal bone a short distance from the region of the scalp wound. On removing the calvarium, an area of inner table is found missing (*Fig.* 462), the fragments (*Fig.* 463), five in number, having been driven through an irregular tear in the dura adjoining the longitudinal sinus, the side of which has been torn into. One of the large veins entering the sinus (anastomotica magna) has been torn across, and the vessel is densely thrombosed (*Fig.* 464). The tear in the arachnoid measures 2 by 3 cm. The longitudinal sinus contains an ante-mortem clot, which extends forward from the site of the injury about 5 cm. Over the entire posterior hemisphere on the right is a thin superficial subdural clot. The left hemisphere appears normal. On section (*Fig.* 465), there is found a large area of cerebral disorganization, with a clot the size of a pigeon's egg in its centre. The bone fragments were found driven into the brain to a depth of 5 cm., just short of the ventricle.

An experience of this kind makes one hesitate to say that an intact skull should not be trephined, particularly when it overlies the longitudinal sinus. In view of his holding out so long, had this unfortunate man been brought in sufficiently early, an operation in all probability would have saved him.

We will return, when discussing the next group of cases, to the question of trepanation even when there is apparently an intact skull, for it cannot be too often or too emphatically emphasized that the essential feature of these cases is not the condition of scalp or skull, but the concomitant injury of the brain. One may find, indeed, that a scalp wound has left even the pericranium intact, and yet that the pericranium conceals a cranial fracture (cf. *Case* 10).

The configuration of the wound, unreliable as appearances are, is a more valuable index of associated cranio-cerebral lesions than its size, which varies from the smallest point, easily overlooked, to multiple wounds or to single

defects of huge dimensions. Some of the most seriously lacerated scalp wounds in the series were apparently produced by the helmet; for, when guttered by a large missile, the incurved edges of metal may plough through the scalp like a harrow, and lacerate it extensively. Indeed a man was admitted to an adjoining hospital with two incurved flaps of the helmet, reamed out like tin before a can-opener, actually penetrating the skull, so that the helmet was caught in the skull as though by a pair of tongs, and had to be cut away.

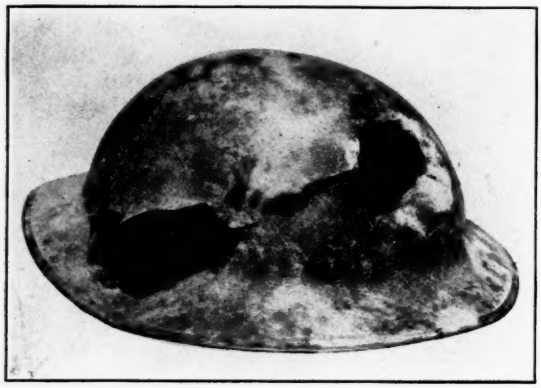


FIG. 466.—Perforation of helmet associated merely with scalp wound.

The largest scalp wound in the series was ploughed out in this way by the helmet (*Fig.* 466). It extended from the parietal eminence forward to the hair margin, a distance of 17 cm., and at its centre the lacerated area was 7 cm. in width. The skull was not even scratched, and the patient practically without symptoms, but the wound was too large to close.

Much more might be said concerning scalp wounds produced by projectiles, and the difficulties of being sure of their nature without operative investigation. On one occasion, after we had made a number of mistakes both ways, a wager was laid between the disputants regarding a certain wound which, though of the gutter type, appeared trifling and superficial, with no neurological symptoms. At operation, the fracture shown in *Fig.* 480 (p. 579) was disclosed.

Briefly, we may say that, unless disproved by investigation, a fracture may be supposed to underlie every scalp wound made by a projectile.

Group II.—LOCAL FRACTURES WITH INTACT DURA, WITH OR WITHOUT CEREBRAL CONTUSION.

In warfare it is naturally taken for granted that a cranial fracture is accompanied by a wound of the scalp; in other words, that it is a compound or open fracture occasioned by a projectile. This is usually, though not always, the case, for many extensive fractures of the skull occur from other causes—from falls, from being buried, or a heavy missile may impart to a helmet a sufficiently diffuse blow to cause a widespread fracture without external injury.

By far the larger number of wounds, however, are produced by an impact more or less local in its effect, with circumscribed injury to the scalp, bone, and brain, and one may make almost any number of subdivisions of these local cranial injuries.

In my former paper already referred to, they were divided into two groups: (1) Those in which the area of depressed bone showed the mosaic

of fragments more or less adherent; and (2) Those in which the fragments were detached and showered into the brain. The reason for making this distinction lay in the fact that the former type is usually, though not always, accompanied by an intact dura, and the latter with a lacerated membrane, the purpose of the paper having been to emphasize the particular risks to life associated with dural penetration.

In the present paper these various local injuries may be analyzed a little more closely, for the character of the bony injury must always remain a matter of interest, and have some influence upon any classification, even though the injury to the brain is admittedly the factor of chief importance.

The series contains 54 examples of local cranial injury which fall in this group: 28 of *Type A* (cf. diagram, p. 562), with the external table practically intact, with or without a verified depression of the inner table; 26 of *Type B*, with depression of both tables. In the latter type trepanation is indicated, even in the absence of neurological symptoms; in the former type trepanation must rest on one's judgement in the individual case.

An intact dura was certified by trepanation in 38 of the 54 cases, 29 of them having shown definite intracranial symptoms. The dura was presumably intact in the remaining 16 which were not trephined. These 16, in short, showed merely a simple graze or fissure of the bone, and, in the absence of neurological manifestations of a local contusion, they were treated as simple scalp wounds, with excision and closure without trepanation.

All of the 26 cases of *Type B*, with depressed external table, were trephined; neurological evidences of a focal lesion were pre-existent in 15, and in 6 the intact dura was incised owing to the disclosure of a local contusion, with 1 fatality. In contrast to this, 13 of the 28 cases of *Type A*, showing merely a graze or fissure of the outer table, were trephined owing to focal symptoms. A depression of the internal table was found only in 2 cases, but in 3 a large extradural clot was exposed, and in 5 others a tense plum-coloured dura overlying a contusion was found and incised.

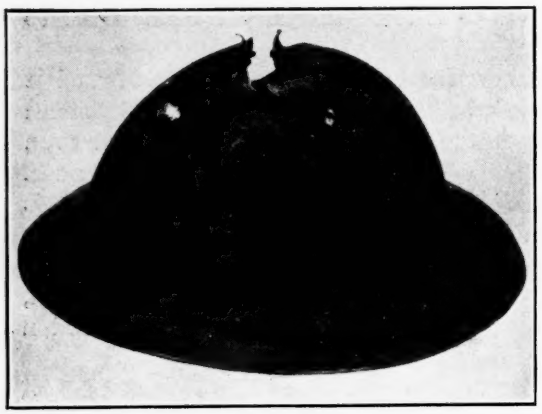
All told, there were 5 deaths in the 54 cases (mortality 9·2 per cent): one from septic bronchitis of gas poisoning, one from a gas-gangrene infection arising from a wound of the upper thigh, one from acute cerebral compression, one from a cerebral infection consequent on opening the dura, one from a secondary cranial operation in a home hospital on a patient with dura unopened at the casualty clearing station. There were, in short, 37 trepanations, with the dura incised in 11 cases, and 2 deaths; there were 16 cases not trephined, with 3 deaths. It will be seen from the case reports that some of the patients whose dura was not incised would probably have done better had the membrane been opened.

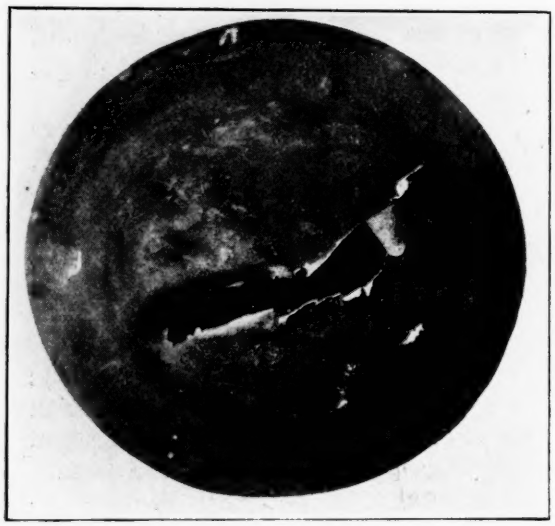
Type A. Local Fractures without Depression of External Table.—For the purposes of our present discussion, these lesser cranial injuries may be subdivided into: (1) Those with or without focal symptoms, but not trephined; (2) Those trephined owing to focal symptoms, but the dura left unopened; (3) Those trephined owing to symptoms, and the dura incised.

1. *Cases not Trephined.*—Three histories may serve to illustrate the first subdivision.

Case 4.—Rfm. S. F. (Serial No. 219).—**Large scalp wound. Mild sinus syndrome. Cranium slightly scored. Not trephined.**

Admission to C.C.S., Oct. 30, 1917, 6.45 p.m.—Wounded in the early morning: a piece of shell caught his helmet and made a deep gutter in it (*Figs.* 467, 468); no loss of consciousness; walked about three miles to field ambulance. Present condition good.





FIGS. 467, 468.—Characteristic guttered helmet of *Case* 4, with scalp wound and slightly scored bone.

Wound. — A large lacerated gutter wound 9 cm. long, obliquely crossing the mid-vertex. No *x*-ray examination.

Neurological Findings.—Some stiffness of the lower extremities, with exaggerated deep reflexes, though without clonus or dorsal plantar response.

Operation, 9.30 p.m. (*circa* 15 hours).—Novocain. Dirty wound edges repaired, disclosing slightly scored bone containing two or three tiny cracks, in one of which a minute metallic foreign body was imbedded. Wound Carrelized and left wide open. Evacuated.

In the next example, owing to the dirty scalp wound and the improbability of its being closable, the skull was not trephined, in spite of the neurological evidence of a local contusion. As will be seen, the restoration of function has been very slow.

Case 5.—Sgt. J. G. (Serial No. 55).—**Mild sinus syndrome. Fissured fracture of vault. Not trephined. Imperfect recovery.**

Admitted to C.C.S., Aug. 16, 1917, 11.15 a.m.—Wounded by a shell at 9 p.m. of preceding day. Wearing helmet. Was knocked down, but not rendered unconscious. Immediate numbness of right foot. On attempt to get up and walk, "leg doubled under him."

General Condition.—Conscious; rational; cold; some headache. Pulse 92.

Neurological Findings.—Fundi slightly œdematous. Paralysis of right leg, with slight impairment of sensation. Right arm slightly weak, though patient attributes this to a former wound. Deep reflexes hyperactive, with slight clonus at right ankle. Plantar responses normal.

Wound.—Large, dirty, lacerated, transverse scalp wound on vertex, measuring 8 by 5 cm., slightly more to left than to right of mid-line. *X* rays show no abnormality.

Operation, 12 noon (15 hours).—Novocain. Excision of extensive scalp wound, disclosing a small fissured fracture directly over mid-line. Wound partially closed.

Aug. 18.—Slight power of flexion regained in right leg, but condition otherwise unaltered. Exaggerated reflexes persist on right. Evacuated.

Subsequent Reports.—Nov. 29 (by letter).—Complaint of dull headache with dizziness on exertion. Paralysis of right leg persisted for about three weeks, and though now able to walk with some stiffness, function has been very imperfectly regained. Dec. 28, report from officer at M.C.H., Hollywood.—Still some muscular weakness in right arm and leg; condition slowly improving. Some headache and dizziness on exertion, otherwise in best of health. Feb. 5, 1918 (by letter).—Complains of numb feeling in leg when he walks far; also of headaches; still in hospital.

The following is another example of the long delay in clearing up of the focal symptoms due to a contused area when the dura has not been opened and the disorganized brain removed. The conditions were favourable for dural incision, but the case occurred fairly early in the series, before this radical measure was often ventured upon.

Case 6.—Pte. S. W. M. (Serial No. 72). **Scalp wound with scored cranium. Not trephined. Persistence of focal symptoms.**

Admission to C.C.S., Aug. 22, 1917, 11.30 a.m.—At 6.30 a.m. was sitting in a concrete dugout which received a direct hit by a high-explosive shell. No loss of consciousness. Walked back one kilometre to an A.D.S., where he was made a stretcher case. Was wearing helmet, which was traversed by shell fragments (*Fig.* 469). Patient volunteers that during the course of the morning his left arm has "kept going dead," though there have been no definite focal seizures.

FIG. 469.—*Case* 6. Showing seriously damaged helmet of patient with but slightly scored cranium.

Condition.—Patient rational; body warm; pulse 64.

Wound.—A triangular-shaped wound to the right of the mid-vertex, supposedly penetrating. *X*-ray report: "No abnormality."

Neurological Findings.—Left arm and leg weaker than right; considerable hypæsthesia to all sensory stimuli; loss of muscle sense; complete astereognosis. Slight nystagmus to right. Deep reflexes within normal limits.

Operation, 2 p.m. (7½ hours).—Novocain. Tripod incision, disclosing a slight excoriation in the parietal bone without linear fracture. Patient not trephined, owing to pressure of more serious cases. Closure without drain. Evacuated.

Subsequent Reports.—Aug. 28, No. 2 Can. Gen. Hosp.—Slight headache; no neurological note. Evacuated to U.K. Sept. 19, Univ. Coll. Hosp.—Persisting weakness of left arm and leg, with loss of muscle sense in left arm. Jan. 1, 1918, Mitchie Hosp., Queen's Gate (by letter).—Weakness of left side subsiding. An *æ*-ray plate reported to show an abscess (probably misread). Feb. 11 (by letter).—Discharged from hospital, Jan. 18; put in Grade B3; on fatigue duty at M.G. depôt; some headaches.

2. *Cases Trephined but Dura Unopened.*—The two following cases fall in the second subdivision. In the first case the external table was intact but the inner was fractured.

Case 7.—Pte. H. F. (Serial No. 73). **Scalp wound of vertex. Mild sinus syndrome. External table intact. Trepanation. Depressed inner table. Dura unopened. Slow recovery.**

Admitted Aug. 22, 1917, 1.30 p.m.—Field ambulance diagnosis: "S.W. vertex. Foreign body removed from scalp. Bone punctured but not penetrated." Remembers receiving a blow on his helmet; found himself buried and unable to move; dazed but not unconscious; was dug out and carried to aid station. In good condition; pulse 90.

Wound.—A contused circular scalp wound in the mid-vertex, exposing bone. No *x*-ray examination.

Neurological Findings.—Considerable weakness of lower extremities, particularly of right, where slight flexion of knee is possible, but no movement of foot. Deep reflexes exaggerated on right, with clonus and positive Babinski.

Operation, 4.30 p.m. (*circa* 10 hours).—Novocain. Scalp wound excised; two minute fragments of helmet lay adjacent to bone. External table intact; trepanation; fragments of inner table wedged down against the sinus; fragments dislodged without bleeding. Dura intact; not opened. Closure with extensive plastic flap.

Post-operative Course.—Aug. 25.—Wound without reaction. Temperature normal. Sutures removed. Aug. 28.—Neurological symptoms continue unaltered; weakness of left foot. Evacuated.

Subsequent Reports.—Sept. 4, No. 10 Gen. Hosp.—No note. Evacuated to England. Jan. 4, 1918 (by letter).—Discharged from service Dec. 20. No neurological symptoms; no headaches; can walk up to six miles comfortably.

One may not only have doubt in regard to the necessity of opening the bone which may appear normal, but at times even the pericranium may be intact and conceal a bony lesion. Occasionally, too, it is very difficult to tell from the external appearances alone whether or not there is actually a fungus cerebri; for a large pulsating blood-clot sometimes may simulate a cerebral protrusion, and the lesion, appearing to be a serious one, may prove to be nothing more than a lacerated scalp wound.

The following case not only illustrates these points, but also the slow restoration of function of a contused area when the dura has not been incised and the pulped tissue removed.

Case 8.—Pte. J. H. (Serial No. 178). **Superficial clot, simulating fungus. Fissured fracture of vault. Trepanation. Extradural clot.**

Admission Oct. 9, 1917, 3 p.m.—A diagnosis had been made of "S.W. head and fungus cerebri." Wounded by shell at 8 a.m.; wearing helmet. Temporary unconsciousness. Walked two or three kilometres to dressing station, the right arm and leg feeling somewhat numb.

General Condition.—Pale; cold; pulse 120, poor quality. Restless; yawning; nauseated. Large dressing soaked with blood. Wound exposed; bleeding, from what was taken to be a large fungus, checked with hot irrigation and pressure. Resuscitation ward: given morphia and saline. Condition improved during night. Pulse dropped to 100.

Neurological Findings, Oct. 10, 9 a.m.—Right arm and hand slightly weak, and "feel numb." Apparent loss of stereognostic and muscle sense, though no loss of common sensation. Deep reflexes hyperactive, without clonus. Normal plantar responses.

Wound.—A large lacerated wound in upper temporo-parietal region, filled with an oozing and pulsating mass. No *x*-ray examination.

Operation (after 25 hours).—Novocain. Wound excised, and found to be filled with a large protruding blood-clot instead of a supposed fungus. Pericranium intact; this was opened and reflected, disclosing a fissure in the bone. Trepanation:

large extradural clot disclosed and evacuated; dura not tense. Closure of large defect by Isle of Man incision (*Fig.* 470). No drainage.

Post-operative Course.—Oct. 12.—Wound clean; sutures removed. Astereognosis persists; condition otherwise excellent. Oct. 14.—Strength in arm largely regained, and disturbance in muscle sense improving. Evacuated.

Subsequent Reports.—Oct. 16, No. 22 Gen. Hosp.—"Loss of position of right hand, with consequent astereognosis. Possibly slight hesitation in speech. Abdominal reflexes depressed on right."

Dec. 29 (by letter).—Discharged from Lord Derby War Hospital, Warrington, Dec. 27; slight feebleness of grip in right hand. General condition "fairly good." Jan. 12, 1918.—Weakness of hand and probably some loss of muscle sense persists; also some hesitation in speech.

FIG. 470.—*Case* 8. Showing three-legged incisions to close large defect. Photograph on second day before removal of sutures.

3. *Cases Trephined and the Intact Dura Incised.*—In this, the most important subdivision, the procedure is unquestionably attended with certain risks of infection, and these one must weigh against the risks of permanent functional impairment if a considerable area of local disorganization is allowed to take care of itself.

There is a widespread impression that under no circumstances should the intact membrane be opened. This impression is born, I am sure, of early experiences in the war when technique was less perfect. Unless the external wound is very septic no great risk is run, provided the membrane is immediately closed with delicate silk sutures. Four of the eleven cases will be given in illustration.

Case 9.—Pte. A. L. A. (Serial No. 216). **Multiple scalp wounds of vertex; linear fracture. Trepanation; dura incised. Recovery.**

Admitted to C.C.S., Oct. 27, 1917, 7.15 p.m.—No history obtainable, owing to patient's condition. In resuscitation ward during night. Transferred to writer's team 1 p.m. on the following day.

Condition.—Stuporous; slight reaction to supra-orbital pressure. Body warm; pulse 88, good quality.

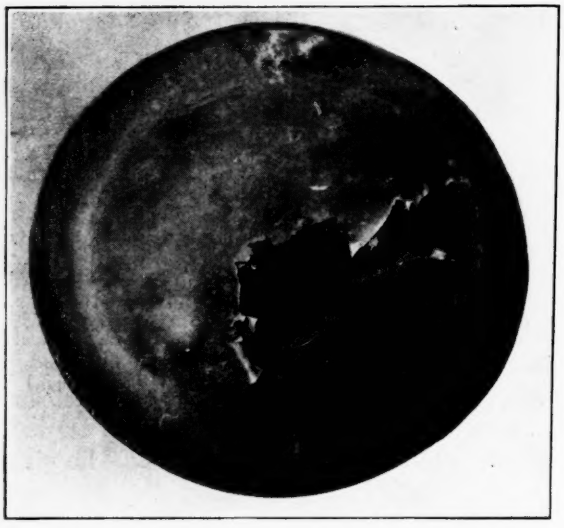
Wounds.—Multiple lacerated wounds of the vertex, chiefly to the right of midline and running in an oblique direction from behind forward, corresponding with the man's injured helmet (*Figs.* 471, 472). *X* rays show a fissured fracture of the right parietal, with no foreign bodies.

Neurological Findings.—Restless; uses right side more than left. Right pupil slightly dilated. Deep reflexes exaggerated on left, with clonus and dorsal plantar response.

Operation, Oct. 28, 3 p.m. (*circa* 24 hours).—Novocain. The two larger lacerated gutter wounds were excised, one of them proving to be merely a scalp wound, but the anterior one overlay a short linear fracture through which blood was

oozing. Circular trepanation, disclosing a tense, discoloured, intact dura. Dura was incised, and about 2 oz. of dark semi-fluid blood-clot was evacuated, immediately lowering the tension. Arachnoid everywhere intact and of good colour. Dura re-sutured.

Oct. 29.—Consciousness regained; responds fully to questions; no recollection of the occurrence nor the events subsequent to his injury. Oct. 31.—Considerable headache. Lumbar puncture: clear fluid in some excess. Nov. 5.—Perfect wound healing. Temperature and pulse



FIGS. 471, 472.—Helmet of *Case* 9, with linear fracture and cerebral contusion.

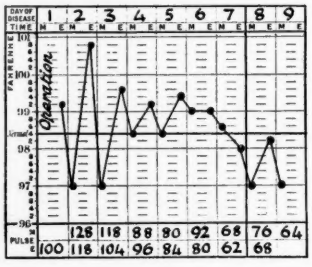


FIG. 473.—Chart of *Case* 9; tendency to slow pulse and subnormal temperature.

tend to subnormal (*Fig.* 473). General condition good. Rapid return of motor power in left side. Evacuated.

Subsequent Report.—Jan. 10, 1918 (by letter).—Still at King George Hospital. Up all day; no trouble with left side. Occasional headache.

In the next example, as in *Case* 8, the pericranium was uninjured and concealed a fracture. The case possibly belongs in reality with the group of bursting fractures, though the bone comminution was centralized under the scalp wound. The patient was in a critical condition, but improved after the evacuation of the disorganized area and subsequent lumbar punctures.

Case 10.—Pte. C. S. (Serial No. 111). **Scalp wound. Intact pericranium. Depressed fracture. Dura incised. Recovery.**

Admission, Sept. 17, 1917, 6.45 p.m.—No story obtainable owing to patient's stupor. Field medical card of same date: "G.S.W skull; compound fracture."

Condition.—Semiconscious; vomiting; pulse 56. Can be roused by supra-orbital pressure, but responses are vague and unintelligible.

Wound.—Ragged gutter type, 8 cm. in length, over right parietal region; supposedly penetrating; a pulsating mass taken to be a hernia cerebri. *X*-ray report: "Fracture of right parietal. No indriven fragments."

Neurological Findings.—Paralysis of left arm and leg, with apparent loss of sensation. Possible weakness of left face, shown on wincing. Tendency to conjugate deviation of eyes, with marked rotation of head to right. Deep reflexes hyperactive, with suggestion of clonus on the left and a positive Babinski.

Operation, 11 p.m.—Novocain. The ragged dirty scalp wound excised: found to be filled with a clot without protruding brain; an intact pericranium disclosed. Pericranium incised, exposing a pond-shaped, slightly depressed fracture with many radiating fissures. Trepanation: removal of the area of depression. Dura intact, but tense and bluish. Membrane incised; large amount of blood-clot, cerebrospinal fluid, and disorganized brain tissue removed. Bleeding vein on the surface of the arachnoid secured with a clip. Dura closed; dichloramine-T; scalp wound closed by plastic flap.

Sept. 18.—Still semiconscious. Lumbar puncture: 20 c.c. of bloody, slightly turbid fluid; culture—coliform bacilli (Captain Leitch). Sept. 19.—Still unconscious. Swallowing badly. Very restless, requiring morphia. Second lumbar puncture: 25 c.c. of fairly clear fluid; culture sterile. Sept. 21.—A series of left-sided Jacksonian fits. Sept. 25.—Responding for first time to-day. Temperature normal. Wound clean. Left hemiplegia still present. Sept. 26.—Moving left leg for the first time. Sept. 27.—Condition excellent, though temperature and pulse tend to be subnormal (*Fig.* 474). Conscious. Responds to questions with intelligence, though no memory of preceding events. Evacuated.

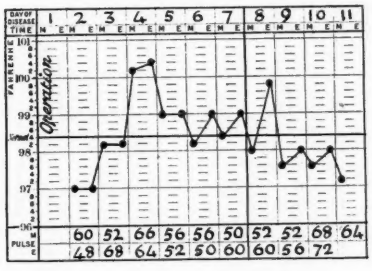


FIG. 474.—Chart of *Case* 10.

The following story records a practically intact skull accompanied by symptoms indicating a local contusion. It is quite likely that this combination may occur more frequently in the temporal region than elsewhere, though, on the other hand, owing to the fragility of the squamous bone, one might anticipate finding a fracture more often here than elsewhere. All this depends doubtless on the structure of the bone in the individual case.

Case 11.—Pte. T. C. (Serial No. 69). **Seton wound through temporal region. Focal symptoms. Cranium practically intact. Trepanation. Dura incised.**

Admission, Aug. 20, 1917, 7 a.m.—Wounded 4 a.m. by shell fragment penetrating helmet. Temporary unconsciousness. Severe headache; dizziness and vomiting. Primary numbness of right arm and leg, followed by weakness.

Condition.—Intellect unimpaired. Body warm. Pulse 68.

Wound.—Glancing wound of left temporal region, with entrance and exit (*plaie en séton*). *X*-ray examination negative.

Neurological Findings.—Weakness of entire right side, with slight hypæsthesia of right face. Some slowness of speech, but no definite aphasia (patient right-handed). Deep reflexes exaggerated and equal; no clonus.

Operation, 11 p.m. (19 hours).—Novocain. Flap procedure; reflection of most of left temporal muscle. Bone slightly scored. Trepanation of an area 3 by 3 cm. Intact dura, tense and bluish. Membrane opened; disorganized brain with many clots evacuated, completely relieving tension. Dura sutured. Flap replaced; sutured in layers. A single gutta-percha drain inserted through unexcised track of missile.

Post-operative Course.—Excellent recovery. No headache; sutures removed and drain withdrawn on second day. Rapid subsidence of right-sided palsy. Temperature and pulse tend to subnormal. Evacuated.

Subsequent Reports.—Sept. 5, No. 8 Gen. Hosp.—Slight weakness of right arm

persists, otherwise normal. Evacuated to U.K. Jan. 10, 1918 (by letter).—In convalescent depôt. Good condition, aside from some headache and dizziness on stooping.

There follows the story of another wound which might easily have passed for a simple scalp wound, but in view of the neurological symptoms indicating a local contusion, not only was the apparently intact skull trephined, disclosing a fracture of the inner table, but an intact dura was opened, with removal of devitalized cerebral tissue.

Case 12.—Pte. H. T. (Serial No. 91). **Trepanation, disclosing depressed fracture confined to inner table. Incision of intact dura. Cleansing of pulped area. Closure. Rapid restoration of function.**

Admission, Sept. 3, 1917, 5 p.m.—Wounded at mid-day by shell fragment penetrating helmet. Knocked down, but not unconscious. Walked fifty yards without assistance, though left side felt numb and dead. In good general condition ; pulse 70.

Wound.—Small, apparently superficial, right parietal region. *X*-ray findings negative.

Neurological Findings.—Patient left-handed ; no apparent speech defect. Tongue protrudes to left. Complete left hemiparesis involving the arm, leg, and lower face. Arm chiefly affected. Complete loss of sense position of left hand, with astereognosis. Deep reflexes active to exaggeration on left, but without clonus. Normal plantar responses.

Fig. 475.—*Case* 12 on discharge, sixteenth day.

Operation, 9 p.m. (9 hours).—Novocain. A vertical incision as for a subtemporal decompression, circumscribing the small scalp wound. Skull apparently intact. Trepanation *en bloc*, 3 cm. in diameter, disclosing fracture with depression of internal table, but an intact dura.

The membrane showed no discoloration or undue tension. It was incised, and a large contusion of the central Rolandic area was exposed, with an abundance of clots, cerebrospinal fluid in excess, and a severely contused area. Careful toilette of this area, with removal by irrigation and suction of clots and pulped brain. Closure of dura ; scalp closed with buried galea sutures ; no drainage.

Post-operative Course.—Convalescence uninterrupted. Highest temperature 99°. Primary healing (*Fig.* 475). Normal sense of position of fingers and hand regained, with ability to recognize objects. Muscle power in arm and leg practically restored. Slight weakness of face persists on expressional movement. By Sept. 19 condition practically normal. Evacuated.

Subsequent Reports.—Sept. 22, No. 13 Gen. Hosp.—No residual paralyses. Condition excellent. Transhipped. Oct. 15, York Military Hosp.—Occasional headaches, otherwise condition normal. Discharged to Sunderland War Hospital. Jan. 1, 1918.—Letter from patient's mother, who wishes to know why a piece of bone from his shin has been put in his head—an unanswerable query. Jan. 20 (by letter).—

Says his hemiplegia has completely recovered except for a slight weakness of left thumb. Bone-graft operation regarded as a great success, but headaches and dizziness on stooping remain unaffected.

This patient doubtless would have recovered from the immediate effects of his injury without trepanation or opening the dura, but the rapid return of function, particularly when compared with other unoperated cases exhibiting similar symptoms, shows the desirability of removing the devitalized cerebral tissue if it can be done with reasonable safety, for there doubtless is very much less reparative reaction afterwards. Cases in which the disorganized brain has been left to care for itself appear to have had a more tardy convalescence and slower restoration of function.

Type B: Local Fractures with Depression of External Table.—These fractures, a few examples of which may be given, offer problems which in many ways are easier, for there can be no question regarding the wisdom of trepanation, whether neurological symptoms are present or wanting.

The following case is of interest in view of the minute size of the foreign body—a fragment of helmet—which seemingly produced the depression and cerebral contusion. The dura was not opened, owing to the infected scalp, and there was a temporary increase in the symptoms after the operation, presumably due to the pressure from œdema about the contused area.

Figs. 476, 477.—Showing outer and inner tables of *Case* 13: dura intact.

Case 13.—Rfm. W. H. (Serial No. 122). **Depressed fracture from minute fragment. Dura not incised. Post-operative increase in local symptoms.**

Admission, Sept. 21, 1917, 2 a.m.—Wound received at 6 a.m. on previous day, soon after going over parapet. Was rendered unconscious; crawled back to a shell hole; bandaged by a companion. Recovered by bearers at 8 p.m.

General Condition.—Conscious; rational; somewhat dull. Pulse 80, good quality.

Wound.—Gutter type, 5 cm. in length; left parietal eminence; edges indurated and infected. *X*-ray report: "Fracture of left parietal; indriven bone with minute intracranial metallic foreign bodies."

Neurological Findings.—Fundi œdematous. Weakness of right arm, without sensory disturbance. Deep reflexes exaggerated; equal.

Operation, Sept. 21, 3 p.m. (33 hours).—Novocain. Excision of septic scalp wound. Exposure of small depression of external table ; minute fragment of helmet imbedded. Trepanation *en bloc*, disclosing unexpected degree of comminution of inner table (*Figs.* 476, 477). Dura intact ; bluish, but no great tension. Not opened, owing to infected scalp. Closure without drainage.

Sept. 22.—Numbness and weakness of right arm very much more marked to-day. Considerable headache. Sept. 23.—Condition satisfactory. Evacuated.

Subsequent Reports.—Sept. 30, No. 2 Stationary Hosp.—Sutures removed ; perfect healing. No neurological note. Evacuated to England.

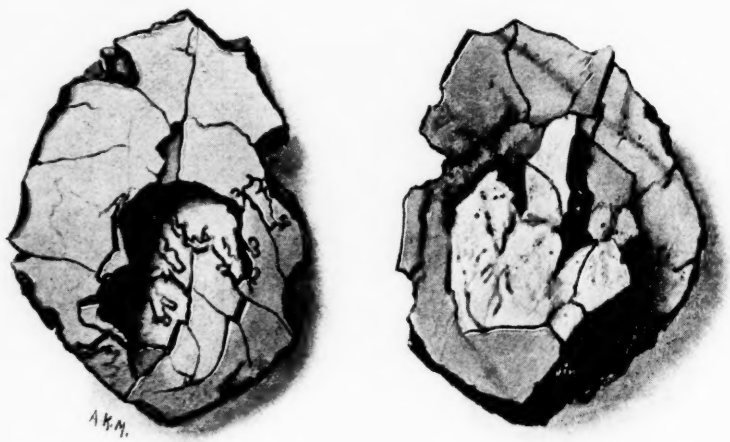
Another example may be given of the consequences of not opening the dura when local symptoms indicate the presence of a cerebral contusion. As is not uncommon under these circumstances, there was a post-operative increase of the paralysis, associated with Jacksonian fits.

Case 14.—L.-Cpl. H. W. (Serial No. 138). **Gutter wound. Compound depressed fracture. Local symptoms. Dura not incised. Increase of symptoms, with focal epilepsy.**

Admission, Sept. 26, 1917, 1.45 p.m.—Wounded 10 a.m. by rifle ball (?). Wearing helmet. Knocked down, but not unconscious. Subsequently severe headache ; numbness and weakness of left side ; was able to get back to A.D.S. with aid of a prisoner.

General Condition.—Good ; body warm ; pulse 98.

Wound.—Lacerated gutter type, 8 cm. in length, extending from right frontal eminence backward and toward mid-line. *X*-ray report : "Depressed fracture, with linear fissures radiating toward vertex and occiput. Small metallic fragments at site of depression."



FIGS. 478, 479.—Showing outer and inner tables of *Case* 14 : dura intact.

Neurological Findings.—Optic discs œdematous, with obliteration of cup, laminæ, and nasal margin. Right pupil larger than left ; tendency to conjugate deviation of eyes to the right. Weakness of left arm, leg, and face, without sensory loss. Deep reflexes brisk and equal.

Operation, Sept. 26, 6 p.m. (8 hours).—Novocain. Excision of scalp wound, disclosing a depressed area (*Fig.* 478) from which many linear fractures radiate. Block trepanation. Inner table fragmented and much depressed (*Fig.* 479). Dura intact. Extradural clots removed. Partial closure.

Sept. 28.—Lumbar puncture : fluid clear. General condition good, although left arm more helpless than before. Sept. 30.—Repeated attacks of focal epilepsy,

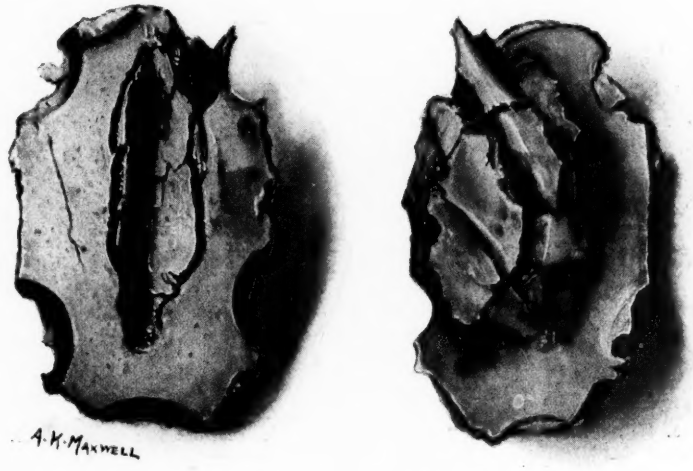
chiefly in shoulder-girdle muscles, associated with turning of the head and eyes to the left. Paralysis of left arm complete. Extensive subconjunctival ecchymosis. Sutures removed. Wound in good condition. Oct. 3.—Occasional recurrence of focal attacks ; general condition good ; paralyses unaltered. Evacuated.

Subsequent Reports.—Oct. 6, No. 16 Gen. Hosp.—Persisting weakness of face and arm. No seizures noted. Evacuated to U.K. Jan. 2, 1918, Fair Lawn Auxiliary Hospital (by letter).—Some slight persisting numbness in fingers, and occasional twitching in left face ; otherwise regards himself as well. Feb. 27, Lond. Gen. Hosp.—Focal epilepsy ; discharged permanently unfit.

There follows the story of what was supposed to be a simple scalp wound ; indeed, as heretofore stated, a wager to this effect had been placed. A depressed fracture without dural injury was disclosed. As there were no focal symptoms, the membrane was not opened.

Case 15.—Pte. S. H. W. (Serial No. 6[2]). **Extensive depressed fracture of occipital region over torcular. No focal symptoms. Dura intact; not incised.**

Admission to C.C.S., Aug. 16, 1917, 7.30 p.m.—Wounded at 11.30 a.m. by shell fragment ; stunned but not unconscious. Made his way back on foot, reaching the field ambulance at 3 p.m.



FIGS. 480, 481.—Showing outer and inner tables of *Case* 15 : dura intact.

Condition.—Conscious ; rational ; warm ; pulse 80.

Wound.—An inverted V-shaped scalp wound in mid-line over occiput. *X*-ray report : " No foreign body ; questionable fracture."

Neurological Findings.—Practically nil. No hemianopsia or visual disturbance. Deep reflexes equal ; exaggerated ; without clonus.

Operation, Aug. 17, 11 a.m. (24 hours).—Novocain. On excising the supposed scalp wound, a depressed gutter fracture (*Fig.* 480), directly overlying the torcular, was exposed. Trepanation *en bloc* disclosed a widely depressed area of inner table, with fragments indriven to a depth of 1 cm. (*Fig.* 481). Dura intact. Closure without drainage. Immediate evacuation.

Subsequent Reports.—Sept. 12, No. 3 Gen. Hosp.—No complications. Primary healing. Evacuated to U.K. Nov. 12, Military Hospital, Richmond.—Boarded out as P.U. Occasional slight headache. No other symptoms. Jan. 9, 1918 (by letter).—Discharged from service Nov. 15, 1917. Feels perfectly well. " Advised to wear a celluloid plate to protect head."

Another example may be given of the rapid disappearance of symptoms following incision of the dura and evacuation of the underlying softened and contused area. The cranial wound was relatively insignificant.

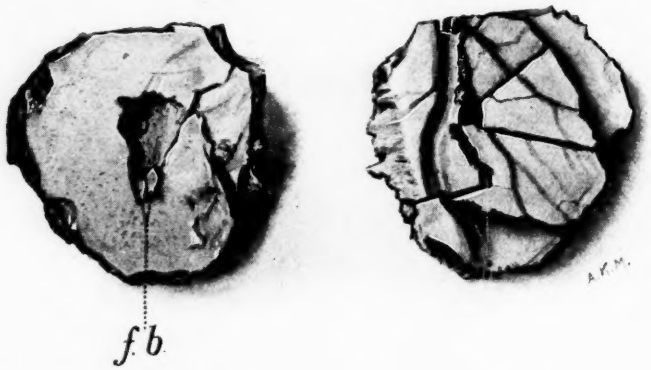
Case 16.—Pte. J. F. (Serial No. 173). **Small compound depressed parietal fracture. Focal symptoms. Intact dura incised. Recovery.**

Admitted Oct. 4, 1917, 11.50 p.m.—Accompanying diagnosis: "Bullet wounds of head and neck. Fractured skull." Oct. 5, 9 a.m.—In resuscitation ward during night. Imperfect history. Wounded some time in the afternoon. Wearing helmet (?). Temporary unconsciousness (?). Present condition good, though somewhat confused and drowsy. Headache.

Neurological Findings.—Left pupil dilated. Weakness and lowered sensitivity of entire right side, involving face and leg, but most marked in arm, with loss of muscle sense and astereognosis. Memory and orientation defective. Slight difficulty in finding his words. Deep reflexes sluggish; equal.

Wounds.—(1) Of penetrating type, 3 cm. to left of mid-line over fronto-parietal region; (2) Multiple small penetrating wounds, right face and neck. *X*-ray report: "Depressed fracture, with indriven bone fragments and multiple small foreign bodies both in cranial wound, face, and neck.

Operation, 3 p.m. (*circa* 23 hours).—Novocain. Usual three-legged incision; small depression found in outer table, with fragment of helmet wedged in the bone



FIGS. 482, 483.—Showing outer and inner tables of *Case* 16: dura intact.

(*Fig.* 482). Radiating lines of fracture pass to the side. Trepanation *en bloc*: widely depressed area of inner table adjoining deep groove of meningeal artery (*Fig.* 483). Dura intact, though somewhat tense and bluish. Linear incision of membrane, with evacuation of about 30 c.c. of semi-fluid clot and pulped brain; expulsion aided by the patient's coughing. Dura re-sutured after usual toilette of cavity by suction and irrigation. Multiple wounds elsewhere individually treated.

Oct. 11.—First dressing: wound perfect (*Fig.* 484); sutures removed. Normal power regained in face and leg; arm less awkward. Oct. 14.—Arm greatly improved; lost sense of position largely restored with present capacity to recognize objects. Deep reflexes remain very sluggish. Evacuated.

Subsequent Reports.—Oct. 16, No. 18 Gen. Hosp.—"Excellent condition. Slight weakness of right hand. Evacuated." Jan. 9, 1918, 4th London Gen. Hosp.—Normal condition, except for trace of weakness in hand.

The Fatal Cases.—There were 5 in the series of 54: a mortality of 9·2 per cent. Two fatalities occurring early in the series—one due to failure to open the dura, the other to the fact that it was opened but not immediately

closed—were avoidable, had better judgement been exercised. A third case was practically moribund when operated upon. The fourth and fifth died of concomitant lesions.

The first fatality in this group occurred six weeks after the injury, subsequent to an operation in England for a cerebral abscess that had formed below the intact dura which had not been incised.

FIG. 484.—*Case* 16. Example of tripod incision.

Case 17.—Sgt. R. D. K. (Serial No. 11).

July 31, 1917.—Multiple wounds of head and face, including depressed fracture of right parietal region. Left hemiparesis, chiefly of arm. Removal piecemeal of depressed bone-fragments; dura intact; not incised. Evacuated Aug. 6.

Subsequent Reports.—Aug. 14, No. 83 Gen. Hosp.—Condition good; wound healed; some headache; evacuated U.K. Oct. 11, King George Hosp.—Death from meningitis following operation for abscess in right hemisphere.

The second fatality was clearly attributable to the surgical opening of the dura—or more properly to the failure to close the incision. A staphylococcal infection of the external wound spread to the meninges.

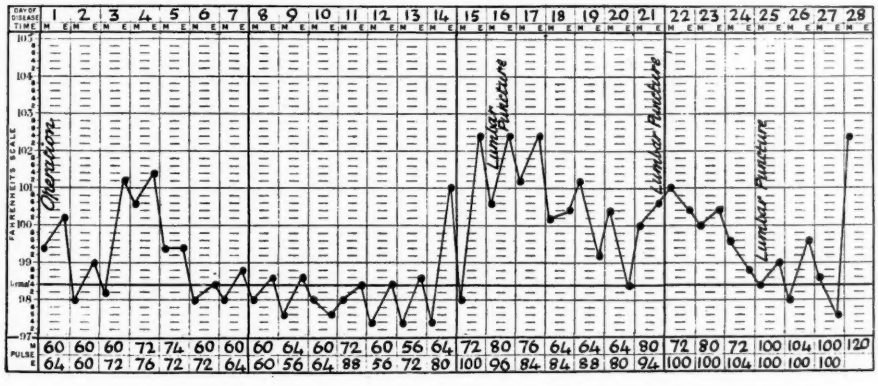


FIG. 485.—Chart of *Case* 18, showing onset of complication on thirteenth day.

Case 18.—Pte. J. L. (Serial No. 59).

Aug. 17, 1917.—Admitted unconscious; pulse 52. A transverse gutter wound of occiput. Novocain operation: linear fracture without depression; tense plum-coloured dura; membrane incised; toilette of greatly pulped left occipital lobe. Dura not sutured. Closure of scalp wound by plastic flap.

Aug. 20.—Consciousness regained. Right homonymous hemianopsia disclosed. Slight necrosis of edges of flap from imperfect circulation. Aug. 27.—Flap protruding. Aug. 31.—Cerebrospinal leak, with rise in temperature (cf. chart, *Fig.* 485). Urotropin. Sept 2.—Lumbar puncture: *Staphylococcus aureus*. Sept. 7.—Lumbar puncture: a coccus in diplococcal form. Sept. 11th.—Cerebrospinal leak continues, but symptoms of meningitis are less marked. Lumbar puncture: clear yellowish fluid, sterile. Temperature normal. Sept 13.—Sudden rise in temperature. Death.

Autopsy.—Cerebrospinal spaces filled with plaques of purulent exudate.

The third fatality occurred a few hours after a futile attempt to save a desperate case by decompression.

Case 19.—Pte. McD. (Serial No. 185).

Sept. 25, 1917.—Unconscious; stertorous breathing and rapid pulse. Gutter wound of vertex, with rigidities. Choked disc 2 D. Right subtemporal decompression; no anæsthetic. Death in two hours; temperature 105°.

Autopsy.—Gutter wound of scalp; external table intact; inner depressed; dura intact; brain widely contused and œdematous.

The fourth fatality was attributable to multiple wounds and severe gas poisoning, as follows:—

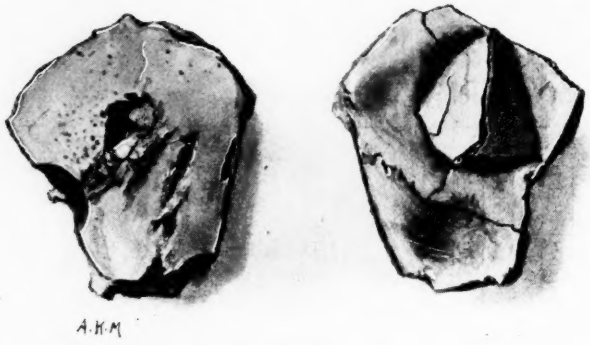
Case 20.—Pte. A. B. (Serial No. 157).

Sept. 19, 1917.—Lying-out case; severely wounded and gassed two days ago. Condition critical; pulse 120; temperature 102°; vomiting. Severe wounds of arm and shoulder; three gutter wounds of scalp. Resuscitation ward for six hours; bicarbonate.

Operation.—Amputation of arm; temporary repair of scalp wounds, without closure. Death in 24 hours, pulmonary complication.

Autopsy.—Purulent bronchitis; bronchopneumonia; depressed fracture of skull in occipital region; dura intact; contusion of occipital lobe.

The fifth fatality was due to a gas-bacillus infection of buttocks and thigh.



FIGS. 486, 487.—Showing small depression (fatal) of *Case* 21: dura intact.

Case 21.—Gnr. A. J. (Serial No. 195).

Oct. 19, 1917.—Perforating wound of upper thigh; large gutter wound of left occiput, appearance simulating fungus cerebri; right homonymous hemianopsia.

Operation (*circa* 36 hours).—Novocain. Trepanation *en bloc*; minute depressed fracture (*Figs.* 486, 487); dura tense, plum-coloured; incised; extrusion of much clot and pulped brain; closure of dura; dichloramine-T; closure of scalp by flap. Repair of infected gassy wound of upper thigh; recovery of large 50-grm. shell-fragment; free excision of damaged muscles; drainage. Rapidly spreading gas infection of thigh and buttock, with death on following day.

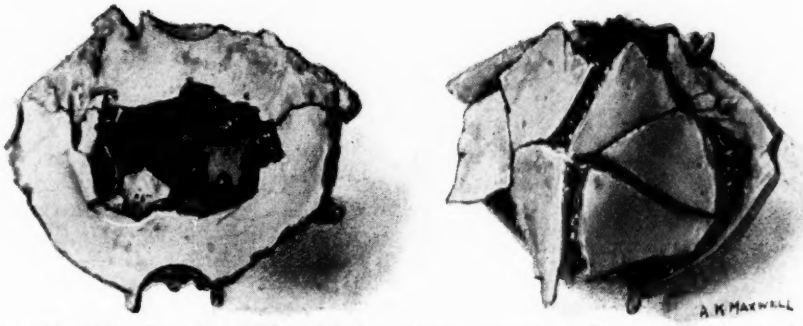
Autopsy.—Extensive gas infection of upper thigh and buttock; brain without evidence of infection.

Group III.—WOUNDS WITH LOCAL DEPRESSED FRACTURES, LACERATION OF THE DURA, AND CEREBRAL CONTUSION.

These are favourable cases, in spite of the fact that the meninges have been torn or punctured by a projecting spicule of bone. Hence they may be considered in a group by themselves, for even though the scalp wound may be grossly contaminated, there is no immediate risk of intracranial infection establishing itself, since the more or less intact mosaic of bone fragments remains interposed between the external wound and the brain, and extrusion of brain substance is uncommon.

Usually both tables are depressed, though this is not invariable, for, as in the preceding group, the bone may merely be fissured or scored, or indeed be intact. It is not improbable that many fractures of this type remain unverified, particularly when the lesion overlies the mid-vertex and is accompanied by the so-called longitudinal-sinus syndrome, in the presence of which Sargent and Holmes have advised against trepanation.

The series contains 18 examples of certified fracture of this type, with 2 fatalities, one of them from intercurrent causes. One may conclude, therefore, that the prognosis is almost as good as in the cases of depressed fracture



FIGS. 488, 489.—*Case* 22. Mid-occipital fracture: mosaic of depressed fragments intact.

without punctured dura, provided there are no serious complicating injuries. For this reason these cases have been separated from those with dural penetration of other forms in which the prognosis is grave.

Anatomically, the wounds were distributed as follows: parietal (including vertex) 8, occipital 4, frontal 4, temporal 2. The associated scalp wounds were of the following types: gutter 10, seton 1, penetrating 7; five of the cases had seriously complicating wounds elsewhere. The missiles, so far as recorded, were: shell fragment 13 (9 certified, 4 presumable), rifle ball 2, shrapnel 1, bomb 1, secondary missile 1; in depressed fractures of this kind it is not uncommon to find the missile lodged in the seat of fracture. The helmet was recorded as worn in 12, not worn in 3, uncertain 3; it was known to have been penetrated in 5, presumably penetrated in 4, and in 2 the missile passed below it.

Occipital Wounds.—The following is a good example of the *Group III* type of injury. It is the only one of the occipital cases in which there was no gross disturbance of central vision.

Case 22.—Seaman E. L. (Serial No. 202). **Mid-occipital depressed fracture; double slight laceration of dura; cerebral contusion slight. Recovery.**

Admitted, Oct. 22, 1917, 3 p.m.—History of receiving an H.E. shell-wound at 11 a.m., while in the line. Was wearing helmet. Knocked down, but not unconscious. Made his way back unaided, though having headache and occasional vomiting.

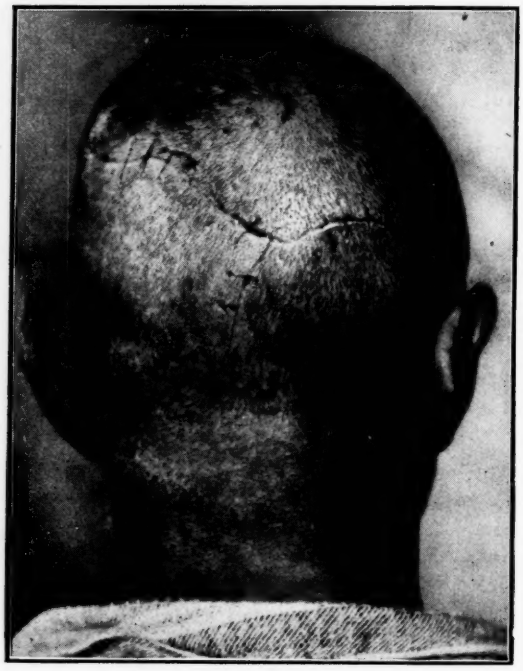


FIG. 490.—*Case* 22. Showing wound with tripod incision on evacuation; sixth day.

General Condition. — No shock; fully conscious; pulse 84, regular.

Wound.—Lacerated, of penetrating type, over the mid-occiput. *X*-ray report: A depressed fracture; no metal.

Neurological Findings.—Nil: no apparent constriction of visual fields.

Operation, 5 p.m. (6 hours).—Novocain. Tripod incisions encircling wound; depressed fracture of the outer table (*Fig.* 488), lying directly over the mid-line. Preparations made for muscle graft, as hæmorrhage from sinus was anticipated. Trepanation *en bloc*; mosaic of depressed inner table intact (*Fig.* 489); marked depression of the underlying dura, with a small laceration on each side of the sinus, the main channel itself uninjured; graft unnecessary. Closure of wound in layers.

Oct. 28.—Convalescence uninterrupted. Wound without reaction (*Fig.* 490). Patient up; no symptoms. Evacuated.

Subsequent Reports.—Dec. 12 (by letter).—At No. 7 Canadian General Hospital two days; evacuated to Seaforth Military Hospital in Leith—eleven days. Transferred to an Auxiliary Red Cross Hospital for three weeks, and after ten days at home returned to his base: Class B2. Some tendency to headaches and dizziness. Feb. 17, 1918 (by letter).—In good health; on service in Italy.

In the three other occipital cases in the group the usual neurological evidences of an injury in this region were present. One of them had a complete central blindness, and the other two a sharply-cut hemianopsia.

The example of complete blindness occurred in an officer (Serial No. 104) with a shell wound which penetrated his helmet. There was immediate complete loss of vision. He was operated on after about ten hours, and under an intact pericranium a stellate depressed fracture over the lambda was found, with a tear in the dura. There was no very evident contusion of the occipital lobes. Light perception began to be regained after forty-eight hours, after which it continued to clear very rapidly to normal.

The other two cases showed hemianopsia; both had lesions over the lateral sinus. In one of them the cerebellum was damaged as well as the occipital lobe. The case follows:—

Case 23.—Pte. W. A. G. (Serial No. 93). **Gutter fracture of right occiput; laceration of occipital dura and lateral sinus. Cerebellum contused under intact dura; incised. Recovery.**

Admission, Sept. 3, 1917, 7.25 p.m.—Wounded at 10 a.m. Was wearing helmet, and states that the projectile (shell fragment) went below it.

General Condition.—Good, though somewhat dull and vague mentally.

Wound.—Vertical, of deep gutter type (*Fig.* 491), behind right mastoid. Some bleeding from external ear. *X*-ray report: Depressed fracture with indriven bone.

Neurological Findings.—Sharply-cut left homonymous hemianopsia. Deep reflexes brisk to exaggeration. No cerebellar symptoms detected beyond slight nystagmus.

Operation, Sept. 4, 10 a.m. (24 hours).—Novocain; cerebellar table. Excision of scalp wound; reflection of sub-occipital flap, showing an occipito-petrosal comminution, with indriven fragments. Piecemeal removal of the fragments disclosed a penetration of the dura over the occipital lobe, with a marginal tear of the lateral sinus, which was secured by a silver clip. The sigmoid sinus was also injured by a large loose fragment, which was not dislodged, as efforts to do so caused a sharp venous hæmorrhage. One large detached fragment apparently opened into the middle ear. Through the dural opening a large amount of disorganized brain with blood-clots was cleaned out by the usual method. Dura over cerebellum very tense and bluish; membrane incised, with evacuation of a large blood-clot and bloody cerebrospinal fluid; incision closed. Scalp wound closed with single gutta-percha drain.

FIG. 491.—*Case* 23. Gutter wound of occipito-mastoid region with occipital and cerebellar contusions.

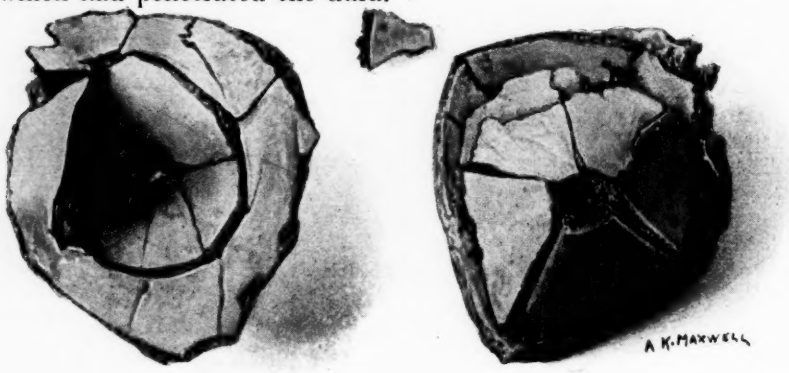
Sept. 19.—Perfect wound healing; normal temperature. Convalescence complicated by a small carbuncle on the neck: excised. Sept. 21.—Condition excellent. Some apparent return of vision in the left visual fields. Evacuated.

Subsequent Reports.—Dec. 22, King George Hospital (by letter).—Occasional headaches; deaf in right ear. Slight remaining contraction of field of vision. No other neurological symptoms. Jan. 20, 1918.—A series of boils have detained him in hospital. Discharged unfit, owing to contracted vision.

Feb. 16.—At work: well, except for some headaches and persisting deafness of right ear.

Frontal Wounds.—Taking the series as a whole, it is our impression that the occipital cases are apt to do less well after operation than frontal ones. The frontal wounds are more accessible, surgically speaking, and despite the mental disturbance which may accompany them, and the tendency of the patients to disarrange their dressings, they have usually done well.

The following case is an example of a depressed frontal fracture, with intact mosaic of fragments except for the dislodgement of a small central piece which had penetrated the dura.



FIGS. 492, 493.—Operative block of *Case* 24, showing depression with intact mosaic except for one central detached fragment which was driven through dura.

Case 24.—Sgt. W. T. (Serial No. 175). **Frontal gutter wound; depressed fracture; mosaic incomplete; dura penetrated. Recovery.**

Admission, Oct. 9, 1917, 11 a.m.—Wounded by a shell while in the reserve line, at 7 a.m. Missile passed below helmet. Knocked down; stunned; consciousness not lost. Walked back to dressing station; severe headache; vomited once.

General Condition.—Good. Pulse 78. Fully conscious and oriented.

Wound.—Of gutter type; left frontal. *X*-ray report: "Depressed fracture with slightly indriven bone. No foreign body."

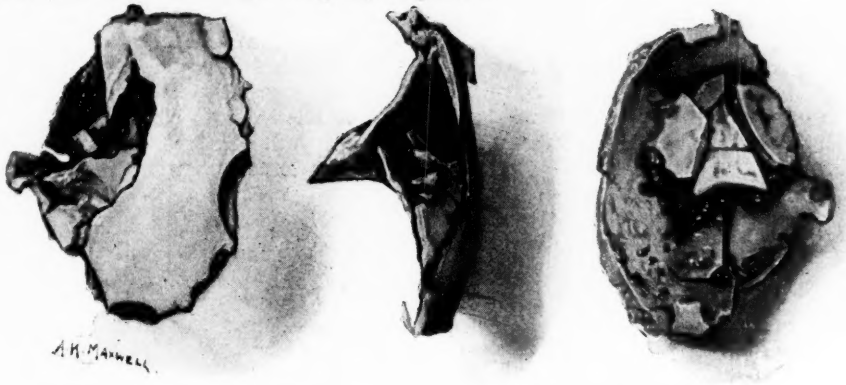
Neurological Findings.—Negative. Deep reflexes brisk to exaggeration.

FIG. 494.—*Case* 24. Showing wound on tenth day: tripod incisions nearly invisible.

Operation, 3 p.m. (8 hours).—Novocain. Tripod incisions encircling gutter scalp wound. Trepanation *en bloc* (*Figs.* 492, 493); mosaic of depressed inner table shows small central fragment missing. Small tear in dura, through which missing fragment with clots and disorganized brain was expressed by coughing. Usual toilette of cavity by suction and irrigation. Closure of tear in dura with single suture. Closure of scalp as usual in two layers. No drain.

Oct. 19.—Uninterrupted convalescence. Superficial sutures removed on second day; incisions practically invisible (*Fig.* 494). No neurological symptoms. Evacuated.

***Subsequent Reports.*—Oct. 20, No. 11 General Hospital.—Condition normal. Evacuated to England. Dec. 12, Princess Christian Hospital.—Quite normal: fit for employment. Feb. 14, 1918 (by letter).—Has received discharge: feels perfectly well, but thinks his memory is slightly impaired.**



FIGS. 495, 496, 497.—Three views of trepanation block from *Case* 25.

The disposition of the bone fragments in these cases of local depression naturally varies greatly. A fragment may be completely dislodged as in the foregoing, or a sharp spicule may penetrate the dura. If it should have punctured one of the venous sinuses, and the common method of removal, piece by piece, is practised, on withdrawal of the penetrating fragment a sharp hæmorrhage may occur, which is difficult to control owing to the inaccessibility of the bleeding point. This is one reason for strongly advocating the method of block trepanation, for under these circumstances full exposure of the field is immediately secured on tilting up the block, and free access is given to the point of laceration.

FIG. 498.—*Case* 25. Showing wound on first dressing with distant drain.

***Case* 25.—Sgt. A. R. (Serial No. 80). Frontal gutter wound; depressed fragment puncturing brain. Recovery.**

***Admission*, Aug. 27, 1917, 9.30 p.m.—Injured at 2.30 p.m. in front-line attack. Helmet pierced by projectile. Temporary loss of consciousness; walked back to his regimental aid post. Severe headache. No vomiting. Good general condition; fully conscious; pulse 86.**

Wound.—A 5-cm. gutter wound, crossing mid-frontal region above supra-orbital ridge. *X*-ray report: "Depressed fracture with indriven fragments."

Neurological Findings.—Negative; no loss of memory; no disorientation.

Operation, Aug. 28, 10 a.m. (20 hours).—Novocain. Excision of gutter wound, disclosing a small depression of external table, with radiating lines of fracture (*Fig.* 495). Trepanation *en bloc*, disclosing a depressed fracture of inner table, with complete mosaic, though one tilted fragment had penetrated dura and brain (*Figs.* 496, 497). Clots and disorganized brain were cleared away by the usual technique. Closure of wound, with single gutta-percha drain, led in from above.

Sept. 2 (*Fig.* 498).—Sutures and drain removed. Temperature still slightly elevated, but wound appears intact. No symptoms. Sept. 9.—Temperature normal; good condition. Evacuated.

Subsequent Reports.—Oct. 24, Bradford War Hospital.—Occasional headache; dizziness on stooping. Invalided. Feb. 17, 1918 (by letter).—In good health; at work.

In contrast to the foregoing, an example may be given of a local fracture possessing quite different characteristics owing to the thicker and less brittle skull. From the outward appearance of the bone a much more serious condition was anticipated than was actually found, otherwise so large a block would not have been removed. The specimen shows well the not uncommon outward dislodgement of plates from the external table as well as indriven inner table—a form of cranial injury characterizing gutter wounds of certain types of skull with a heavy vault.

FIG. 499.—*Case* 26. Showing wound before operation.

Case 26.—Pte. A. T. (Serial No. 89). **Frontal gutter wound, with elevation of external and depression of internal tables. Dura punctured. Cerebral contusion. Recovery.**

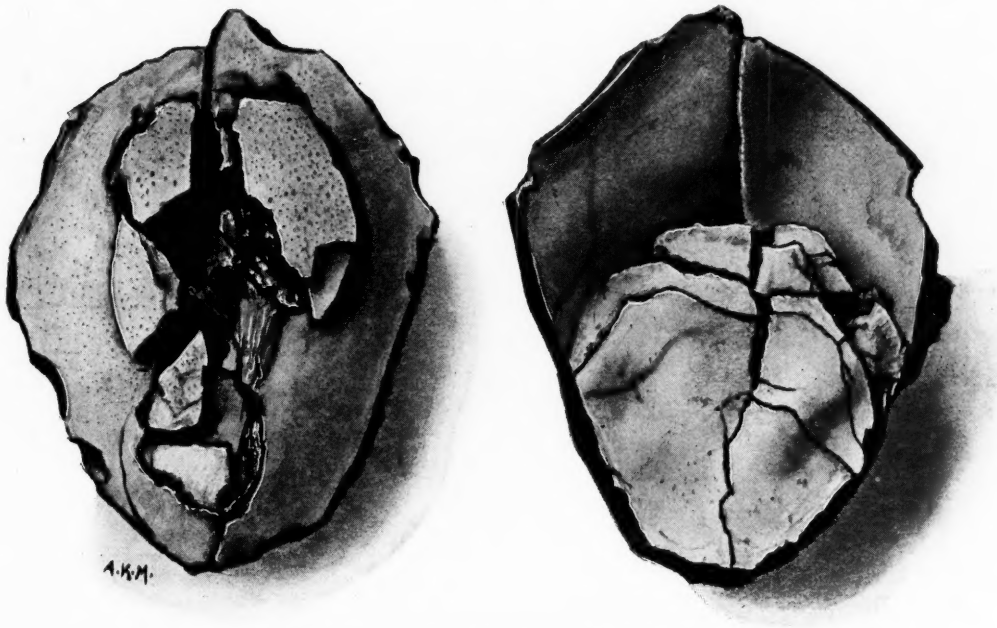
Admission, Aug. 31, 1917, 9.30 p.m.—In a dugout at 4 p.m., without helmet; wounded by shell explosion. Rendered unconscious; roused later, and got back unaided. Resuscitation ward during night; wound Carrelized. Sept. 1, 9 a.m.—Excited; irritable; talking loudly. Pulse 80, good quality. Some mental confusion and disorientation.

Wound.—Gutter type, 5 cm. in length, slightly to left of mid-line at frontal eminence (*Fig.* 499). *X*-ray report: Shows questionable fracture. Complicating wound of right forearm.

Neurological Findings.—Fundi show œdema, with blurring of nasal margins. Mental excitement, otherwise no symptoms of note.

Operation, 10 a.m. (18 hours).—Novocain. Tripod incisions circumscribing scalp wound; flaps reflected, disclosing a gutter in a very thick skull, with lateral elevation of many fragments of external table and radiating fissures (*Fig.* 500).

Wide trepanation *en bloc*; an intact mosaic of depressed inner table; no great dislodgement of fragments (*Fig.* 501); a laceration in the dura, alongside the sinus,



FIGS. 500, 501.—*Case* 26. Trepanation block showing behaviour of thick skull to tangential wound.

with a large subdural clot and an area of pulped brain. Through the dural opening the disintegrated and softened brain was removed by suction and irrigation. Dural wound sutured. Scalp sutured in two layers; gutta-percha tissue drain.

Post-operative Results.—Sept. 3.—First dressing (*Fig.* 502); sutures and drain removed; slight discharge of pus (staphylococcus) from site of drain. Carrel-Dakin treatment for next five days. Sept. 20.—Wound healed (*Fig.* 503). No neurological symptoms. Condition excellent. Evacuated.

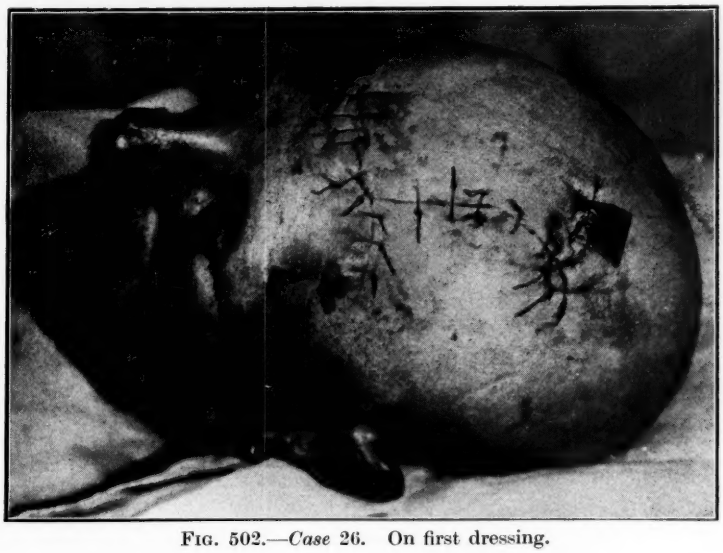


FIG. 502.—*Case* 26. On first dressing.

Subsequent Reports.—Nov. 30, King George Hospital.—No symptoms except some limitation of fields of vision (?) to right. Dec. 13, Gifford House Auxiliary Hospital (by letter).—Some headaches, otherwise

well; discharged unfit for service. Feb. 15, 1918 (by letter).—In best of health; at work.

FIG. 503.—*Case* 26. On discharge.

Temporal Wounds.—The two temporal cases in this group had no special points of interest, except that in one of them a rivet from the helmet acted as a secondary missile.

Parietal Wounds.—Including wounds of the mid-vertex, there were eight parietal cases. Three of the patients had post-operative Jacksonian attacks, a matter to which we will subsequently return. The history of one of them follows:—

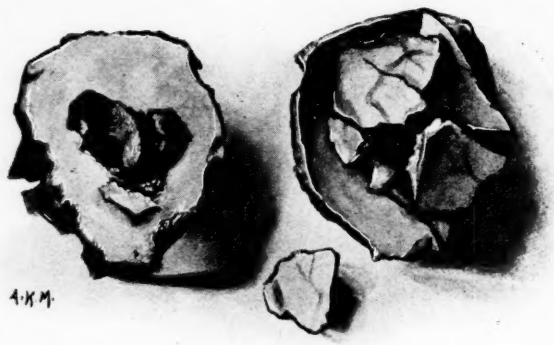
Case 27.—Pte. J. H. T. (Serial No. 163). **Depressed fracture, with dislodged fragment of inner table. Cerebral contusion. Post-operative convulsions. Recovery.**

Admitted, Oct. 3, 1917, 2.30 a.m.—Wounded by a bomb fragment three hours previously. Numbness and weakness of his left arm noticed immediately.

Wound.—Small, penetrating type, 4 cm. to right of median line in plane vertical to auditory meatus. *X*-ray report: "Depressed fracture with indriven bone."

Neurological Findings.—Marked weakness with some loss of common sensation in the left hand; normal sense of position. Slight weakness of left leg. Deep reflexes exaggerated on the left; no clonus; normal plantar responses.

Operation, 11 a.m. (12 hours).—Novocain. Tripod incision. Area of small depressed fracture encircled and elevated, showing depression of inner table, with one fragment of mosaic missing (*Figs.* 504, 505). A tear in the dura disclosed the two large veins (vena anastomotica magna), one of which had been cut across by the dislodged fragment near its point of entrance into the lateral expansion of the sinus. Vein bled profusely on elevating the bone disc; it was secured immediately with a clip. Parietal lobe considerably pulped; usual toilette, with irrigation and suction. The missing bone fragment was detected by the catheter at a depth of 2 cm., and removed. Tear in the dura sutured without freshening its edges; dichloramine-T spray; closure of scalp without drainage.



FIGS. 504, 505.—*Case* 27. Bone disc with fragment missing from inner mosaic.

Post-operative Results.—Oct. 6.—Wound without reaction (*Fig.* 506); sutures removed. For the past three days many and persistent Jacksonian attacks in the left arm and hand, where there is now complete loss of power and muscle sense. Weakness also of face and leg. Definite sensory impairment also over left arm and leg. Oct. 9.—General condition excellent, though arm remains paralyzed, and left leg weak. Evacuated.

Subsequent Reports.—Oct. 15, No. 20 General Hospital.—Evacuated to England. Dec. 10, King George Hospital.—No motor or sensory disturbance present. No headaches. Discharged, unfit for service. Jan. 2, 1918 (by letter).—Now back at work; feels no ill effects from his injury.

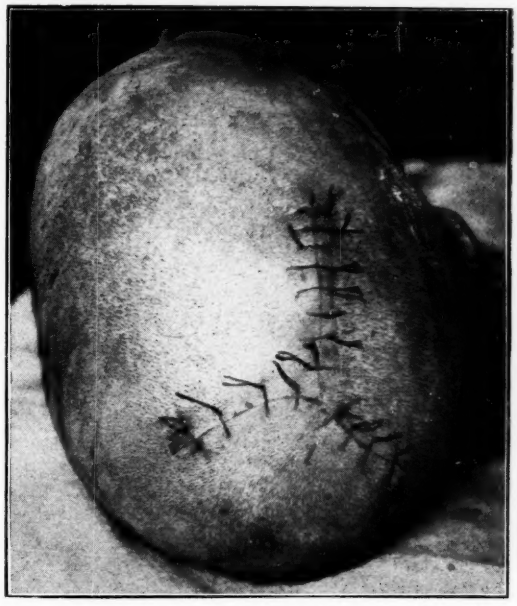


FIG. 506.—*Case* 27. Tripod incisions on third day.

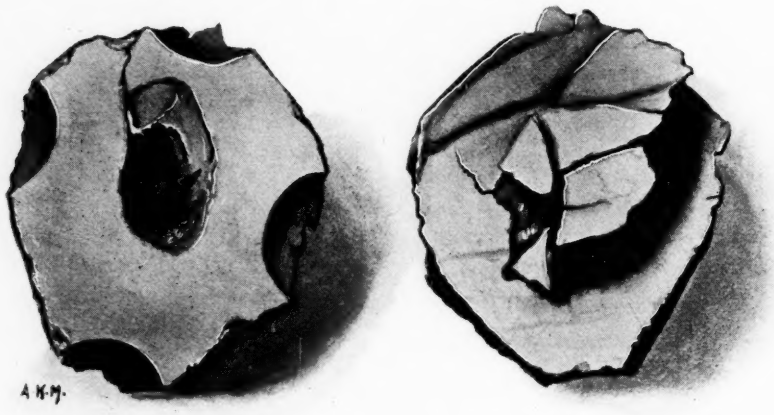
It is quite probable, in explanation of the post-operative increase in the paralyses in this case, that some bleeding occurred, with refilling of the cavity. Such an accident, however, is rare, even in these parasinoidal cases, particularly when they have been operated upon under a local anæsthetic. When they have been given inhalation narcosis, vomiting may so increase venous tension as to start up bleeding which appeared to have been checked.

In one other patient (Serial No. 75) with a lesion quite similar to the foregoing, Jacksonian attacks also occurred. The case furnishes an interesting example of a direct hit on a helmet (*Fig.* 507) where the skull escaped with a slightly depressed inner table (*Figs.* 508, 509), a lacerated dura, and considerable pulping of the parietal lobe. The wound was closed as usual without drainage, and the patient did well, but for three or four days after the operation there was an almost continuous twitching and spasm of the left arm. Whenever any voluntary effort was made to move the hand, a typical Jacksonian attack would originate in the thumb and extend up the arm to the shoulder. The attacks subsided, and there was no recurrence; this fortunately is the usual history of these early post-traumatic examples of focal epilepsy.

FIG. 507.—Serial No. 75. Penetrating injury of helmet (natural size). Cf. *Figs.* 508, 509.

The wound in two of the parietal cases lay directly over the longitudinal sinus in the mid-vertex; one of them (Serial No. 58) was without

symptoms—no demonstrable spasticity—though the dura was lacerated and the hemisphere contused. Momentary active hæmorrhage from the sinus followed elevation of the bone disc, but the bleeding was easily checked by a muscle graft, and a good recovery followed.



FIGS. 508, 509.—Serial No. 75. Slightly depressed fracture (cf. helmet, *Fig.* 507).

The following case showed symptoms more characteristic of a lesion in this neighbourhood. The operation—one early in the series, and under a general anæsthetic—was imperfectly carried out, and a late abscess developed.

FIG. 510.—*Case* 28. Perforation of helmet by rifle ball, producing seton wound of vertex.

Case 23.—Pte. T. B. (Serial No. 25). **Seton wound of vertex. Hemiparesis, with focal epilepsy. Imperfect operation. Late abscess. Recovery.**

Admission, Aug. 2, 1917, 11 a.m.—Wounded at 8 a.m. on the previous day by a sniper, the ball perforating his helmet (*Fig.* 510). No loss of consciousness, nor headache, but his left hand and foot immediately felt numb and weak. About twelve hours later he began to have Jacksonian seizures in his left side, originating in the leg and lasting four or five minutes, without loss of consciousness.

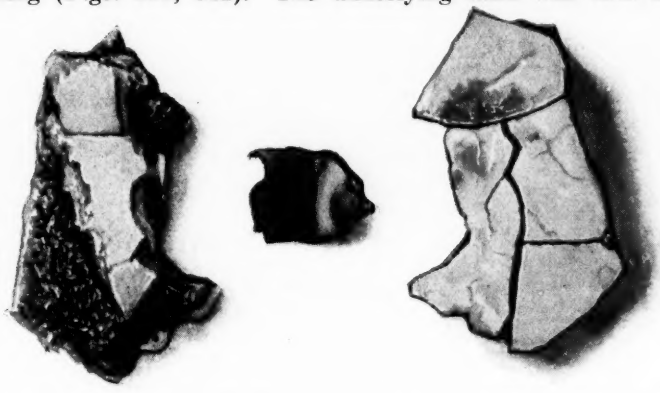
General Condition.—Conscious; rational; pulse 88.

Wound.—Of entrance and exit, 5 cm. apart, in the mid-vertex, the exit wound being slightly to the right of the mid-line. *X*-ray report: "Depressed fracture of mid-vertex, with radiating fissure in skull running posteriorly. Superficial foreign body."

Neurological Findings.—Left hemiplegia, with extreme spasticity and rigidity of lower extremity, the arm being somewhat less involved. Right leg weak and

somewhat rigid. Deep reflexes exaggerated both right and left, with ankle clonus, less well sustained on the right; positive Babinski both right and left. Deep reflexes of arms exaggerated on left, normal on right. Frequent focal seizures, which begin in muscles of the left thigh, and cause powerful and painful contractions of the leg in adduction and flexion, with clonic jerking. By the time of his operation he was unable to move his left arm or leg, and slight weakness in the left face was apparent.

Operation, 2 p.m. (30 hours).—Ether. Scalp wound excised, exposing a deep gutter fracture extending slightly to the right from mid-line; a portion of the jacket of the rifle ball wedged in the fracture; bone much fragmented; one large plate of depressed bone consisting of both tables was lifted out from over the sinus without causing bleeding (*Figs.* 511, 512). The underlying dura was torn and the brain



FIGS. 511, 512.—*Case* 28. Outer (left) and inner (right) surface of single central depressed fragment; also bit of jacket of rifle ball removed from gutter.

greatly pulped; clots and disorganized cerebral tissue were expressed largely by pressure on the surrounding dura; no attempt made to thoroughly empty cavity. Closure by plastic, with lateral drain.

Post-operative Results.—Aug. 5.—Repeated, though lessening, Jacksonian attacks occurred for past three days; some movement has returned in the leg. Temperature practically normal (*Fig.* 513), despite a right pleurisy. Aug. 9.—Wound infected (staphylococcus); partly opened and Carrelized. Aug. 13.—Wound still discharging. General condition excellent. No fungus. Right side remains practically paralyzed, without sensory loss. Evacuated.

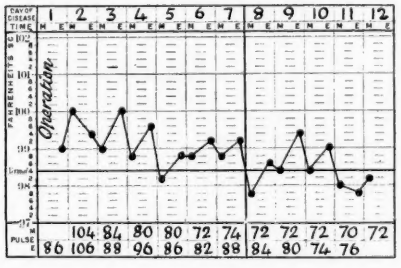


FIG. 513.—*Case* 28. Temperature chart.

Subsequent Reports.—Sept. 8, No. 11 General Hospital.—Wound practically healed; small sinus. Neurological condition unchanged. Evacuated to England. Dec. 30, King George Hospital.—Abscess developed, and was opened Nov. 1. Good recovery. At present regaining movements in shoulder and arm. General condition good. No further Jacksonian attacks. Jan. 23.—Up and very much improved: arm and leg gaining strength.

The Fatal Cases.—Two occurred in this group—both parietal cases, both early in the series.

Case 29.—Gnr. A. W. B. (Serial No. 4).

July 25, 1917.—Serious condition from multiple wounds: penetrating wound

of thorax; fracture of spine, with paraplegia; gutter wound of left parietal, with contralateral symptoms in arm.

Operation.—Ether. Hurried repair of all three injuries. Depressed fracture of skull; dura penetrated; severe contusion of parietal lobe. Death on eighth day.

Autopsy.—Meningitis; double bronchopneumonia; fracture of spine.

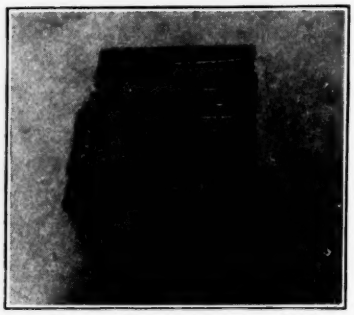


FIG. 514.—*Case* 30. 23·42-grm. shell fragment (natural size) of a 5·9 shell.

Case 30.—Sgt. E. B. (Serial No. 44).

Aug. 11, 1917.—Lying-out case, twenty-four hours. A ragged infected right parietal wound; a large shell fragment (*Fig.* 514) wedged in a depressed fracture; dura lacerated.

Imperfect operation, under ether; flap method; incomplete toilette of greatly contused parietal lobe. Wound infection (*B. perfringens*); fungus cerebri. Death third day.

Autopsy.—General meningitis; encephalitis.

Group IV.—FRACTURES WITH DISLODGED BONE FRAGMENTS PENETRATING BRAIN, USUALLY WITH EXTRUSION OF CEREBRAL SUBSTANCE.

Here we come to a more serious type of injury, one in which fragments, often of both tables—contaminated fragments consequently—are widely indriven. There is apt to be a considerable defect in the skull, through which cerebral substance extrudes, adding greatly to the probability of infection.*

The external wound accompanying this type of lesion is usually of the tangential (gutter) variety, though it may be produced by a direct blow from an indented helmet, or the helmet may be penetrated and the missile be found in the superficial wound or lodged in the bone. It will be seen that *far the larger number of these wounds occur over the parietal area* or its junction with frontal or occipital fields.

All told, 39 cases fall in this category. The scalp wounds (often the cranial wound as well) were tangential in 25 cases, ragged, more or less circular wounds in 8, of the small penetrating type in 5, and *en séton* in 1. An extrusion of cerebral substance from the wound, or direct exposure of the brain, was recorded in all but 12 of the case-histories.

The wound was over the parietal area in 27 of the 39 cases (including parieto-frontal 6, parieto-occipital 3, and mid-vertex 5), over the occipital area in 8, frontal area in 3. It is to be noted, in contrast to the anatomical site of the wounds with a lodged projectile (*Group V*), that there were no temporal or occipito-cerebellar wounds.

As might be surmised from this description of these injuries, the exact *nature of the missile* producing them can only be conjectured in the larger number of the cases. Moreover, men with these more serious injuries had no

* There may, of course, be considerable overlapping of these groups, and such a case as that described earlier in the paper (*Figs.* 461–465), with fragments from the inner table showered well into the hemisphere though the external table remained intact, would hardly fall in this group so far as risks of infection are concerned, though it would naturally be placed here on the basis of the accompanying cerebral injury.

interest in bringing in their damaged helmets, and the stuporous condition of 12 of them on admission precluded any history whatsoever. In 19 cases there was a definite history of the helmet being worn; in 5 it was not worn, two of these being bombing accidents. The missile was identified as a shell fragment in 5 cases, shrapnel ball in 1, grenade in 3. One officer felt confident that a rifle ball had penetrated his helmet, and four others were under the impression they had been hit by machine-gun bullets. It is the type of injury one would expect from a rifle ball penetrating the helmet, but in the confusion of a modern battle a wounded man can hardly be expected to know what has hit him, and unless a fragment has lodged, one can only conjecture what the missile may have been.

In brief, it appears that cerebral injuries of this variety, with indriven bone fragments and escape of bruised cerebral substance, are commonly produced by tangential wounds over the thicker portions of the skull, particularly of the parietal regions. The helmet in all likelihood has been perforated in most cases; the wounds are almost always single; and it is the type of injury that one would expect from a rifle or machine-gun bullet. By just what mechanism the fragments of bone are driven at right angles to the line of flight of the projectile is not entirely clear.

The wounds in most cases are so similar and so characteristic that there is little occasion for subdivisions, though there are two which must be recognized as important: (*a*) *Those in which the fragments lie short of the ventricle* (25 cases); (*b*) *Those in which they have opened the ventricle* (14 cases). The mechanism of the production of the injury is of course the same in both instances, but the distinction is based, as is the distinction between cases with an open or closed dura, more on the all-important factor of potential infection, than upon the rule that the deeper the fragment the more severe the injury.

Taking the group as a whole, there were 12 deaths in the 39 cases (mortality 30·7 per cent), but the far greater seriousness of the ventricle cases over the others can be best shown by separating these types. In 25 examples of the (*a*) type there were 6 fatalities (24 per cent); in 14 examples of the (*b*) type, with the ventricle penetrated, there were 6 fatalities (42·8 per cent).

Inasmuch as one object of this report is to emphasize the effects of the injury upon the brain rather than its effects on the skull, the further discussion of the ventricular cases will be reserved for a later section (*Group VI*), in which they have been placed.

As has been pointed out, the majority of these wounds lie over the parietal vertex, and consequently many are accompanied by grades of what Sargent and Holmes have called the longitudinal-sinus syndrome. This, as I interpret it, is a symptom-complex which indicates a contusion of the vertex in which the mesial edges of both hemispheres participate, leading to a bilateral spastic paralysis of the lower extremities, with possible involvement of one or both arms. The condition is one which has its counterpart in the traumatic spastic paralysis of child-birth—the so-called Little's disease. Occasionally one finds thrombosis of the sinus or entering vessels, but I feel very doubtful as to whether these vascular lesions are the actual cause of the symptoms. The syndrome certainly occurs when there is no evidence

of thrombosis, and the bilateral contusion which is almost inevitably present would seem to be a sufficient explanation.

One interesting feature of these cases is the progressive nature of the symptoms recognized by the victim of the injury, who, after return of consciousness, is aware of weakness in one leg, or leg and arm, and finally the other leg; or in extreme cases both leg and arm become involved. Primary weakness and numbness is succeeded by paralysis and spasticity, with more or less adductor spasm.

The three following cases illustrate severe grades of this syndrome.

Case 31.—Pte. R. W. T. (Serial No. 18). **Transverse gutter injury of mid-cranial vault, with sinus injury and indriven fragments. 'Longitudinal-sinus syndrome.' Operation.**

Admitted Oct. 9, 1917, 8 a.m.—Wounded in early morning of preceding day by shell fragment which traversed helmet. Unconscious for some time. On regaining consciousness found he could not walk; helped into a shell hole and remained all day. During this time he observed that his legs were getting rigid, and also that his arms were beginning to feel stiff and numb. Rescued by bearers late in the evening.

FIG. 515.—*Case* 31. Gutter wound across vertex: sinus syndrome.

General Condition.—Conscious; rational; pulse 100. No shock.

Wound.—Large transverse gutter type, measuring 10 by 5 cm., in posterior parietal region, somewhat more to right side (*Fig.* 515). *X*-ray report: "Fissured fracture of vertex. Bone-fragments indriven. No missile."

Neurological Findings.—Weakness, numbness, and spasticity of all four extremities, more marked in legs, particularly the left. Face not involved. Considerable lowering of sensitivity to pain over legs, though thermal sense fairly well preserved. Some sensory loss also on arms. Definite loss of muscle sense with astereognosis in left hand. Reflexes greatly exaggerated throughout, with bilateral knee and ankle clonus well sustained. A positive, slow, Babinski response on left; equivocal on right, where response is very active. Plantar stimulation on left leads to drawing up of right foot, with flexion of ankle. Vasomotor: left leg and foot cold; right, warm and sweating. A similar condition, though less marked, in the arms.

Operation, 4.30 p.m. (*circa* 34 hours).—Novocain. A long transverse incision, like an autopsy incision, circumscribing the dirty scalp wound. Exposure of an opening in the external table 2·5 cm. in length (*Fig.* 516), extending to the interparietal suture; radiating fissures pass in a coronal direction. Trepanation *en bloc*, disclosing a defect in the dura 2 by 1·5 cm., to the side of the sinus. Fragments of bone and disorganized brain were extruding. On the inner surface of the block were a few loosely attached spicules (*Fig.* 517); other fragments completely separated were carefully withdrawn. The dislodgement of one spicule which had penetrated the lateral wall of the sinus was followed by a momentary profuse bleeding; checked by the placement of three silver clips on the margin of the sinus. The right parietal lobe was greatly pulped. The track made by the indriven fragments was sucked and irrigated by the usual catheter method until the tension completely

subsided. From the bottom of the track at a depth of 5 cm. eight fragments of inner table shown by *x* rays were recovered. A small amount of dichloramine-T

FIGS. 516, 517.—*Case* 31. Bone block showing: *Left.*—Interparietal suture and fissures radiating from gutter; *Right.*—A few fragments of internal table still attached.

was left in the track; the transverse incision was closed in layers, with a single drain of protective tissue let in through a puncture opening (cf. *Fig.* 518).

Post-operative Course.—Oct. 12.—Sutures and drain removed. No untoward symptoms. Oct. 14.—Spasticity of legs subsiding, especially of right, where considerable movement is present. Astereognosis of left arm persists. Evacuated (fifth day). (*Fig.* 518.)

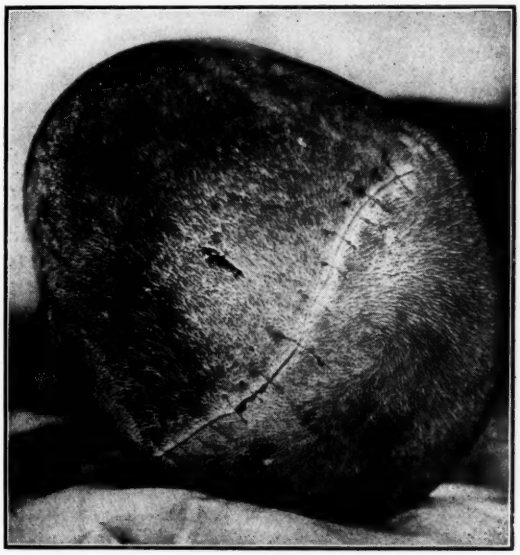


FIG. 518.—*Case* 31. Wound on evacuation; fifth day.

Subsequent Reports.—Oct. 16, No. 11 General Hospital.—"Considerable headache on admission, with choked disc of 1 D. Wound clean. Loss of touch, pain, and temperature sense of all extremities. Left arm weak at shoulder and slightly spastic. Right arm about two-thirds normal. Legs slightly spastic and weak—about one-third normal. Superficial abdominal reflexes absent on left. Deep reflexes bilaterally exaggerated." Dec. 26, Stepping Hill Hospital.—"Progressing favourably; general health good. Arms and right leg largely restored; left leg has good hip, feeble knee, and absent ankle movement, with some dulling of sensation Deep reflexes+ + ."

Feb. 15, 1918 (by letter).—" Still in hospital and improving; left leg still weak, right fairly strong."

It is of course ideal in a case of this sort to close the scalp, but if there has been an obviously imperfect toilette of the pulped brain area, less risk is run by leaving the wound open. Under certain circumstances, therefore, it may be unwise to cover the defect, as in the following case—occasionally it is impossible to do so, as in the succeeding one.

Case 32.—Rfm. W. M. (Serial No. 120). **Gutter wound of vertex, with fungus. 'Longitudinal-sinus syndrome.' Incomplete wound closure, with direct treatment of hernia. Recovery, with residual paralysis.**

Admitted Sept. 21, 1917, 1 a.m.—Wounded on preceding day about 5 a.m. Lay in shell hole all day, unable to crawl back owing to weakness of right side. Severe headache and vomiting. Brought in by bearers.

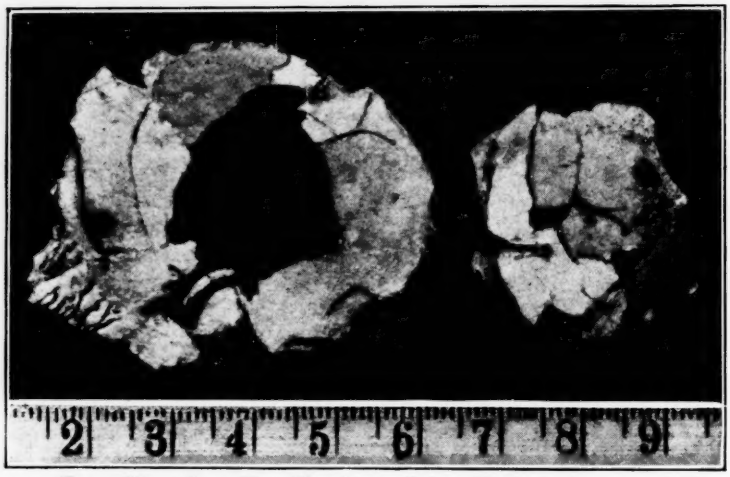


FIG. 519.—*Case* 32. Showing: *Left.*—Much broken up skull; *Right.*—Indriven bone fragments, six in number. Both specimens were pieced together after removal.

General Condition (after 8 hours in resuscitation ward).—Fully conscious. No mental disturbance. Pulse 72. Body warm. Fundi normal.

Neurological Findings.—Complete spastic paralysis of right leg and arm. Face uninvolved. Partial paralysis, with some spasticity, of left leg. Left arm uninvolved. Deep reflexes exaggerated, with bilateral clonus, less well sustained on the left. Positive bilateral Babinski reflex.

Wound.—Of gutter type; slightly to the left of the mid-line of vault. Wound edges infected; a foul-smelling fungus cerebri full of hair and fragments of bone. *X*-ray report: " Fracture, with indriven bone. No missile."

Operation, 10 a.m. (28 hours).—Novocain. Scalp wound encircled and excised. Incisions prolonged in *fleur-de-lys* fashion (cf. *Fig.* 520) in preparation for plastic closure. The flaps were reflected, disclosing an opening in the skull 2 by 2 cm. in diameter, with protruding fungus and many radiating lines of fracture. Skull thin, brittle, with little diploë. Removal *en bloc* of bony area (*Fig.* 519). Pulped area in left upper paracentral region thoroughly cleansed by suction and irrigation; removal of all fragments of indriven bone (*Fig.* 519). Owing to obvious local infection, wound was incompletely closed, leaving an opening directly over the fungus; treated with dichloramine-T.

Subsequent Course.—A small fungus developed, which was dressed daily and treated with dichloramine-T. Oct. 4.—Temporary cerebrospinal-fluid leak, which persisted for forty-eight hours. The small fungus, which never protruded above the level of the scalp, finally subsided, and began to heal over. Patient's general condition remained excellent throughout, and the temperature after the first day was normal (*Fig.* 521). No alteration occurred in the spastic paralyses, and voluntary movement was practically confined to his left arm. Evacuated Oct. 14 (twenty-third day).

Subsequent Reports.—Oct. 16, No. 11 General Hospital.—Condition good. Immediately evacuated to U.K. Dec. 27 (letter from patient, at King George Hospital, written with left hand).—Up on couch, but unable to stand as yet. Jan. 10, 1918 (report from the M. O.).—Wound healed; no headaches; mentality normal. Right arm and leg continue spastic, though considerable return of all movement except at ankle. Chief residual weakness in right hand and foot. Deep reflexes remain + +. Slow though progressive improvement. Feb. 2 (by letter).—Steady progress; taking walking lessons.

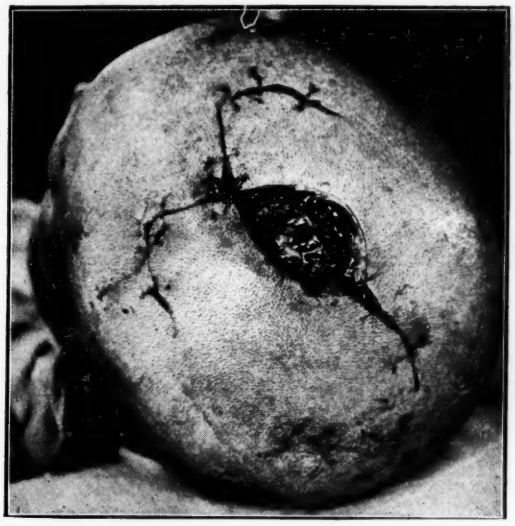


FIG. 520.—Fleur-de-lys incisions; partial closure; fungus left in centre.

Attention may be called to the structure of the cranial vault in the foregoing case; it was comparatively thin and fragile, and had broken into many small pieces like a piece of china; this is in marked contrast to the character of the vault in *Case* 26 (*Fig.* 502).

In the next case, another of this same clinical type, it was impossible to close the wound, though the attempt was made to do so.

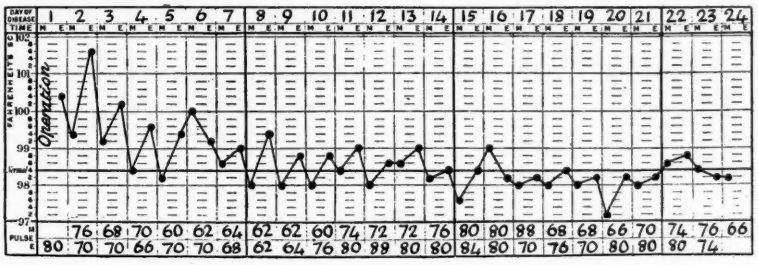


FIG. 521.—*Case* 32. Chart showing regular temperature despite fungus and cerebro-spinal-fluid leak.

Case 33.—Pte. T. T. (Serial No. 180). **Gutter wound of vertex; cerebral herniation; 'longitudinal-sinus syndrome.' Operation, with removal of indriven bone fragments. Scalp wound not closable.**

Admitted Oct. 10, 1917, 1.20 p.m.—Wounded 6 a.m. on previous day. Was wearing helmet. Temporarily unconscious. Lay in shell hole all day. Immediate weakness of entire right side, and gradual of left leg during the course of the day. Brought in by bearers after twenty-four hours. Both legs and right arm have become increasingly stiff, but was able to move the left leg until this morning.

General Condition.—Conscious; rational; no mental symptoms. Pulse 80. Body warm.

Neurological Findings.—Legs rigid, with marked adductor spasm; completely paralyzed. Considerable hypæsthesia, but can distinguish between sharp and dull stimuli, though less well on right than left. Right arm also completely paralyzed and stiff, with considerable sensory loss to pain and temperature. No recognition

of objects placed in hand. Deep reflexes greatly exaggerated throughout, but no clonus elicited. Bilateral dorsal toe-response to plantar stroking.

Wound.—A very wide lacerated gutter wound slightly to the left of the mid-line at mid-vertex. *X*-ray report: "Depressed fracture with indriven bone. No missile."

Operation, 10 p.m. (after 40 hours).—Novocain. Excision of dirty scalp wound with gaping infected edges. Area of involved bone removed *en bloc* from over sinus, disclosing a tear in dura to margin of sinus. Many spicules and plates of inner table removed from about 5 cm. deep in left hemisphere. Devitalized brain area removed by irrigation and suction. A large anastomotic vein, which was uninjured and unthrombosed, bridged over the gap. This was doubly ligated. A large clean cavity was left in the hemisphere. An attempt to close the defect by an extensive plastic was abandoned, owing to the dense and immobile character of the patient's scalp, which could not be easily shifted. Incisions sutured. Protective dressing directly over wound in dura with dichloramine-T.

Post-operative Course.—Oct. 22.—Condition has remained excellent, with normal temperature, despite development of a small fungus. Continued dichloramine-T dressings. Fairly rapid return of movement in left leg. Right side remains paralyzed. Oct. 29.—Some movement returning in right leg at hip and knee, and in right arm at elbow. Deep reflexes remain hyperactive, with clonus on the right. Nov. 16.—Condition progressively improving. Fungus clean. Evacuated.

Subsequent Reports.—Nov. 18, No. 14 General Hospital.—Picric acid dressing. Evacuated immediately to England. Jan. 10, 1918 (by letter from King George Hospital).—Still in bed; fungus not entirely healed; right arm and leg still weak and stiff. Feb. 22 (by letter).—Wound healed; regaining movement in arm and leg.

Another parietal injury which falls in this group was as follows. The wound was of the direct rather than the more common tangential variety, and some interest attaches to the behaviour of the fragments. Large scales of the broken inner table, though fully detached, yet remained adherent to the dura, and through and between them a single fragment of outer table was deeply indriven (cf. *Figs.* 522, 523, 524). A similar occurrence will be met with in a case in a subsequent section (*Group VI, Fig.* 150).

Case 34.—Pte. W. G. T. (Serial No. 74). **Multiple wounds. Depressed fracture; cerebral extrusion; contralateral monoplegia. Operation; removal of deep bone fragments. Recovery.**

Admission, Aug. 22, 1917, 2 p.m.—Wounded by shell at 6 a.m.; apparently no loss of consciousness; walked unaided to aid post. History obtained with difficulty, owing to speech defect.

Condition.—Good; rational; pulse normal.

Wounds.—(1) Lacerated wound, arrow-head in shape, over the left parietal eminence near mid-line; depressed fracture of skull; extrusion of cerebral substance. *X* rays show indriven bone with minute foreign particles. (2, 3) Penetrating wounds of left shoulder and left knee.

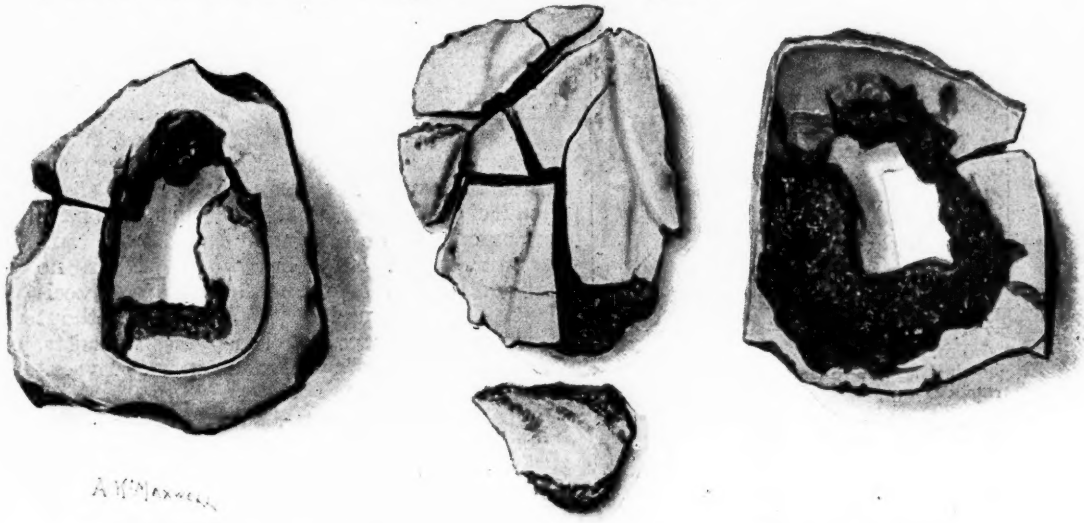
Neurological Findings.—Slight paraphasia: gets words with some hesitation and stammering. Slight weakness of right face; complete paralysis of arm; no apparent weakness of leg. No demonstrable sensory loss; muscle sense normal. Deep reflexes active, equal; without clonus.

Operation, 10 p.m. (14 hours).—Novocain. Tripod incision encircling wound, disclosing depressed fracture (*Fig.* 522), with absence of bone substance and a wide radiating fissure. Trepanation *en bloc*, showing (*Fig.* 523) wide fracture of inner table, with detachment of five large pieces, two of which, together with a fragment of external table, were driven deeply into the brain through a tear (2 by 1·5 cm.) in the dura. Area of brain greatly pulped; thorough toilette. Closure of scalp wound, with single gutta-percha drain. Repair of wound of shoulder and knee.

Post-operative Course.—Aug. 28.—Movement beginning to return in right hand

and arm. Paraphasia practically disappeared. Aug. 31.—Wound perfect; temperature normal. Evacuated.

Subsequent Reports.—Sept. 2, No. 10 General Hospital.—Condition practically normal. Evacuated to England. Oct. 27, 1st Southern Hospital, Birmingham.—Condition normal. Free from subjective symptoms. Slight weakness of right arm. Boarded as permanently unfit. Jan. 26, 1918 (by letter).—No residual symptoms whatsoever; no headaches: expects to resume occupation.



FIGS. 522, 523, 524.—*Case* 34. *Left.*—External table with defect in depression and fissures; *Right.*—Inner table showing marked loss of substance; *Centre.*—Mosaic of fragments of internal table pieced after removal; *Below.*—Single indriven fragment of external table.

An example of a more posterior wound of this same type, with injury of the occipital lobe, follows. The patient had been lying out, and in the face of an infection, possibly too great risks were taken in closing the wound without a drain. Had the presence of gas bacilli on the indriven bone fragments been foretold, drainage would have doubtless been employed. Examples of disaster from closure under these circumstances were not infrequent in the early series, particularly before we came to the routine employment of dichloramine-T in these gas-suspected wounds.

Case 35.—L.-Cpl. W. J. W. (Serial No. 49). **Right parieto-occipital wound, with herniating brain. Dural penetration by indriven bone fragments, showing B. perfringens on culture. Left homonymous hemianopsia.**

Admission, Aug. 14, 1917, 6.15 p.m.—History obscure: patient disoriented. Thinks he was wounded two days ago going over his parapet; wearing helmet. Remembers being brought in by stretcher bearers.

General Condition.—Somewhat stuporous, but can be roused to answer questions. Pulse 60. Severe headache; vomiting. Eyes practically closed by ecchymosis and œdema of lids.

Wound.—A circular, ragged, bad-smelling wound about 3 cm. in diameter over right posterior parietal region. Cerebral substance extruding. *X*-ray report: "Fracture with cranial defect and five indriven bone fragments" (*Fig.* 525).

Neurological Findings.—Right pupil larger than left. Fundi show low grade of papillœdema with obscuration of disc margins. No paralyses detected. Impossible to test for hemianopsia. Normal plantar responses. No abdominal reflexes.

Operation, 8 p.m. (*circa* 48 hours).—Novocain. Excision of scalp wound. Block trepanation, disclosing laceration of dura about 2 cm. diameter, and fungus. Suction and irrigation of track, with removal of the bone fragments from depths of 5 and 6 cm. Complete relief of pressure. Fungating portion of brain bluntly excised. Tripod scalp incisions closed in layers; no drainage.

FIG. 525.—*Case* 35. *X*-ray photograph, showing square defect and five indriven fragments.

Smears and cultures (Capt. Leitch) from a deep bone fragment show bacilli of the perfringens type.

Post-operative Course.—Aug. 16.—Condition excellent. Sharply-cut left homonymous hemianopsia demonstrable. Patient much more alert. Aug. 18.—Normal healing; sutures removed (*Fig.* 526). Still some slight headache. Subconjunctival ecchymoses have appeared. Some continued elevation of temperature (*Fig.* 527), but wound shows no tension. Sept. 5.—General condition excellent. Wound perfectly solid and without tension. Subconjunctival ecchymosis persists, also left homonymous hemianopsia. Evacuated.

Subsequent Reports.—Sept. 12, No. 1 Canadian Hospital.—Some cephalalgia. Wound healed. Evacuated. Jan. 1, 1918, Northumberland War Hospital (by letter).—Condition remains good except for persistence of hemianopsia and occasional headache; up and about; being retained for bone-grafting operation. Jan. 18 (by letter).—Final decision not to operate. Has received his discharge; feels well, and expects to return to his business. Feb. 14.—Doing well, but annoyed by pulsation in defect after exertion.

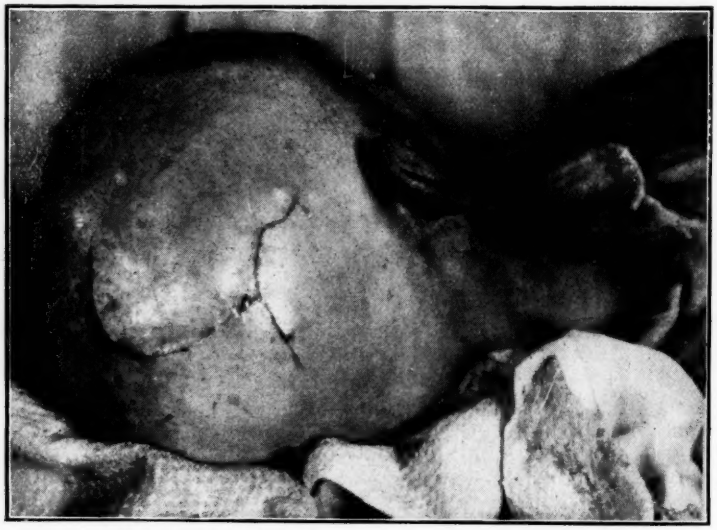


FIG. 526.—*Case* 35. Patient on fourth day.

The following, another parietal lesion, is an example of a direct rather than a tangential hit, with lodgement of the missile in the skull. Under these circumstances the showering of cranial fragments into the cerebrum is easily understood.

The case is an example also of a double cranial injury. The auro-petrosal wound might easily have been the more serious of the two had the dura not

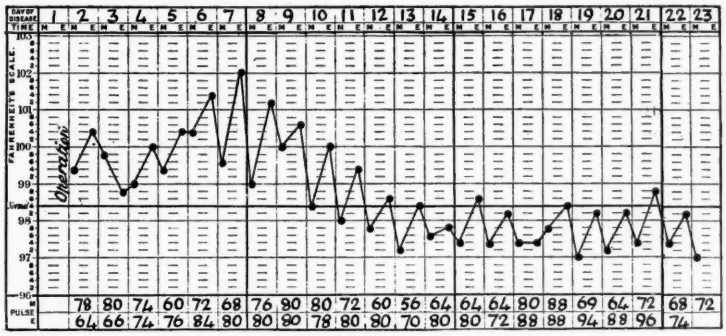


FIG. 527.—*Case* 35. Chart showing irregular temperature though wound remained intact.

remained intact. Had it been torn, the case would properly have fallen in the group of far more serious lesions to be considered later on (*Group VII*).

Case 36.—Pte. G. A. A. (Serial No. 70). **Multiple shrapnel wounds. Superficial lodgement of ball in parietal bone, with fragments projected into brain. Second ball in petrous bone, with intact dura. Recovery.**

Admission, Aug. 20, 1917, 10 a.m.—Probably wounded in early morning attack. No reliable details elicited.

General Condition.—Semi-conscious; can be roused with difficulty; responds vaguely to questions. Is somewhat disoriented. Pulse 60.

Wounds.—Three circular scalp wounds with ragged edges, apparently penetrating: (1) Over left parietal eminence 3 cm. from mid-line; (2) Over left mastoid; (3) Just anterior to the attachment of the pinna; also (4) A perforating wound of right deltoid. *X* rays show two shrapnel balls, one in the parietal bone with indriven fragments, a second in the right petrous bone in line with the auditory canal.

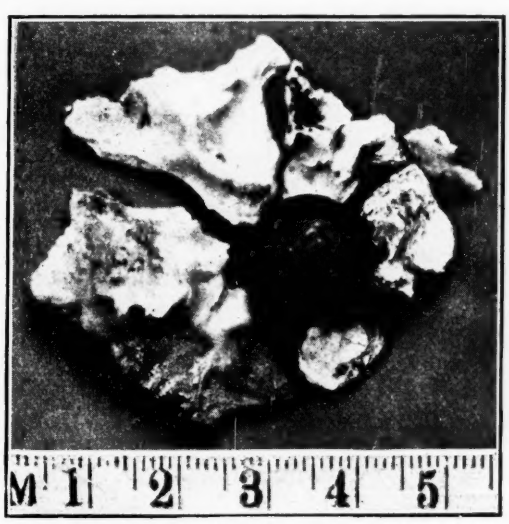


FIG. 528. *Case* 36. Ball from petrous bone with dislodged fragments.

Neurological Findings.—Persistent conjugate deviation of head and eyes to the right. Can be induced momentarily to turn eyes to left; the movement elicits nystagmus. Apparently complete left hemiplegia. Sensory tests unreliable. Deep reflexes not obtained on left; sluggish on right. Normal plantar response on right; sluggish on left.

Operation, 6 p.m. (*circa* 12 hours).—Novocain.

Temporal wounds: A curvilinear incision made incorporating the wounds before and behind left ear; downward reflexion of flap. Wound over mastoid non-penetrating. Under anterior wound is a badly fractured petrous bone, with iron shrapnel ball lodged deeply in the region of the middle ear. The ball was removed, together with many fragments of petrous bone (*Fig.* 528) and pieces of helmet lining. Dura contused, but intact. Closure of flap, with direct drainage through unexcised original wounds.

Parietal wound : Tripod incisions ; ball found lodged in bone (*Fig.* 529), with protrusion of cerebral substance alongside it. Trepanation *en bloc* ; practically all fragments of inner table detached and showered through a laceration in the dura (*Fig.* 530). On dislodging some superficial fragments, much clot and disorganized brain extruded itself. Other fragments were removed from a depth of 5 cm. at the bottom of the pulped area. Careful toilette of cavity ; closure, with direct gutta-percha drain.

Shoulder wound : Excision of lacerated muscle in track ; Carrel-Dakin treatment.

Post-operative Course.—Aug. 22.—Wounds look well ; sutures removed. Some return of movement in left side, which is still very weak. Persisting conjugate

FIGS. 529 530, 531.—*Case* 36. Ball lodged in parietal bone : indriven fragments recovered : one fragment attached to inner surface of block.

deviation of eyes to right ; movement to left brings out nystagmus. Aug. 29.—Wounds practically healed. Moves left leg well ; arm remains paralyzed. Still some nystagmus to the left. Right deafness persists. Evacuated, though some slowing of pulse and somewhat irregular temperature (*Fig.* 532).

Subsequent Reports.—Oct. 3 (by letter from Lord Derby War Hospital).—Was evacuated to England Sept. 9. Wound perfectly healed, now up in wheeled chair. Jan. 10, 1918.—Left leg normal ; free movements of left arm and a fairly good grasp with the left hand, which shows daily improvement. Right ear deaf. Jan. 18.—Has had an aluminium plate, 3 in. by 2 in., inserted by operation over the defect ; dura torn at operation ; two epileptiform seizures followed. Feb. 15.—Up again, and doing well after four weeks in bed following operation ; arm improving.

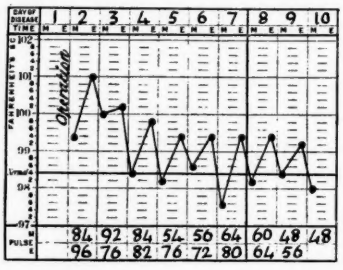


FIG. 532.—*Case* 36. Chart showing slight irregularities though wound remained intact.

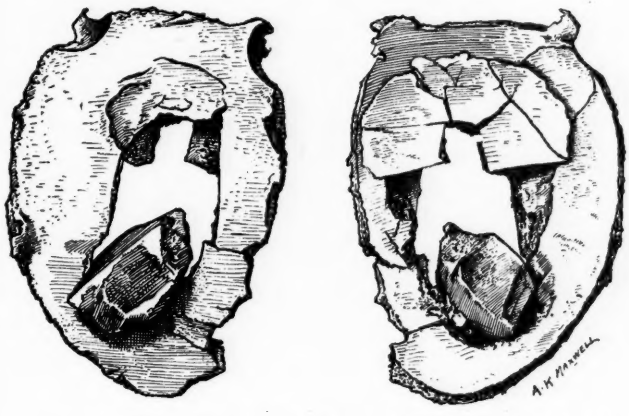
The foregoing story shows that not only gutter wounds, but also direct or oblique impacts with lodgement of the missile, may produce a showering of bone fragments. There was one other case in the series (Serial No. 112) with a parietal wound very similar to the above, in which an 8-grm. shell fragment, showing a burnished surface from helmet perforation, was wedged in the broken skull (*Figs.* 533, 534). The man was discharged on the fifth day with perfect wound healing, and has made a good final recovery.

In the following case there were two cranial wounds of different types—

one a gutter wound with indriven bone fragments, the other a small penetrating wound with intracerebral lodgement of the projectile. The former was regarded as the more serious, and the penetrating wound was treated conservatively and allowed to pursue its own course.

Case 37.—Bdr. W. C. (Serial No. 176). **Multiple wounds. Two cranio-cerebral; gutter wound of left parietal, operated upon; penetrating wound of frontal, no operation. Recovery.**

Admission, Oct. 9, 1917, 11.15 a.m.—Wounded in back area at midnight, while asleep without a helmet. No loss of consciousness; immediate numbness of hand and arm; walked short distance with help; arrived in good condition.



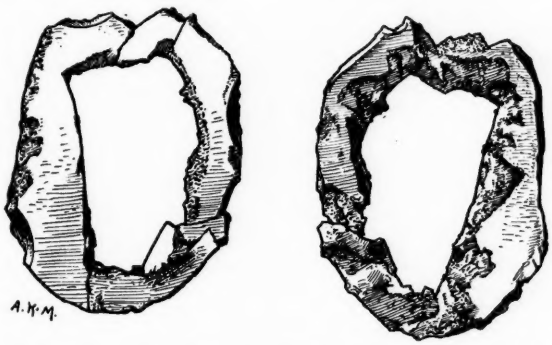
FIGS. 533, 534.—Example of lodged shell fragment: lodged in an oblique gutter wound.

Wounds.—(1) Gutter type, of right posterior parietal; extruding brain; (2) Penetrating type, through right frontal sinus; (3) Penetrating right cheek, with paralysis of lower facial. *X*-ray report: "Depressed fracture of right parietal, with indriven bone; fracture of frontal, with small metal fragment 5 cm. in brain."

Neurological Findings.—Weakness of left face and arm; loss of muscle sense; astereognosis. Deep reflexes + +; equal.

Operation, 2 p.m. (14 hours).—Novocain.

1. Tripod incisions encircling gutter wound. Block trepanation of small depressed gutter fracture (*Fig.* 535) with very dirty fungus. Inner table entirely dislodged (*Fig.* 536), with showered fragments. Bleeding artery on cortex, secured by clip. Usual toilette of pulped track. Dichloramine-T. Tear in dura approximated with single suture. Scalp closed with no drain.



FIGS. 535, 536.—*Case* 37. Small gutter fracture in thin skull; complete dislodgement of fragments.

2. Dichloramine-T treatment of track of frontal wound, which penetrated frontal sinus: no operation.

3. Wound of cheek, penetrating parotid; projectile lodged near angle of jaw. Counter-opening made; through-and-through gutta-percha drain (*Fig.* 537).

Post-operative Course.—No fever; wounds healed well (*Fig.* 538). Rapid improvement in palsy of opposite arm. Evacuated Oct. 14 (fifth day).

Subsequent Reports.—Oct. 19, No. 13 General Hospital.—Evacuated to England, Dec. 7, Oakbank War Hospital.—Paralysis of lower branches of right facial. Slight loss of power in left hand; improving. Evacuated to Auxiliary Hospital. Feb. 15, 1918 (by letter).—Back in the army signal section since Jan. 1: complains of headaches.

Mention has been already made of the fact that the occipital cases have in some respects seemed to be less favourable, or at least more difficult, than frontal ones. We shall see that five of the six fatalities occurred in occipital cases.

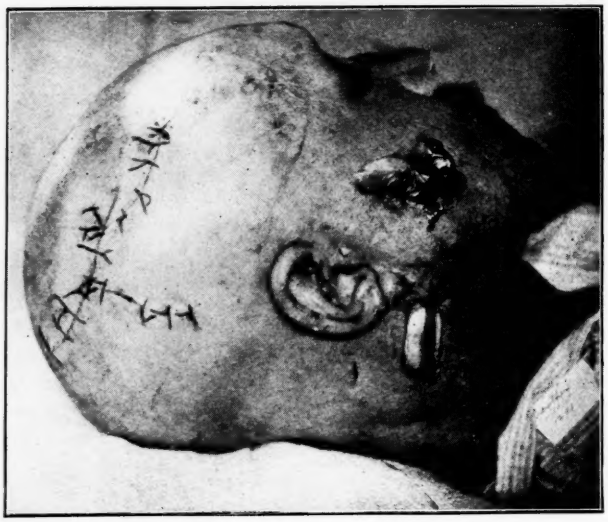


FIG. 537.—*Case* 37. Tripod incisions for parietal wound; second day. Note small swelling over forehead where penetrating wound existed: also parotid drain.

The wound in the following case was parieto-occipital, and, like the foregoing, a transverse gutter wound. It was one of the earlier cases in the series, when we were still attempting to cover defects with flaps.

Case 38.—Pte. P. P. (Serial No. 52½). **Parieto-occipital gutter fracture, brain extruding; indriven bone fragments. Homonymous hemianopsia. Operation: closure by flap. Infected fungus. Recovery.**

Admitted Aug. 16, 1917, 7.20 p.m.—Went over parapet at 5 a.m., wearing helmet; no recollection of subsequent events until being dressed at a field ambulance. Has had nausea and vomiting. Complains that his head is bursting.

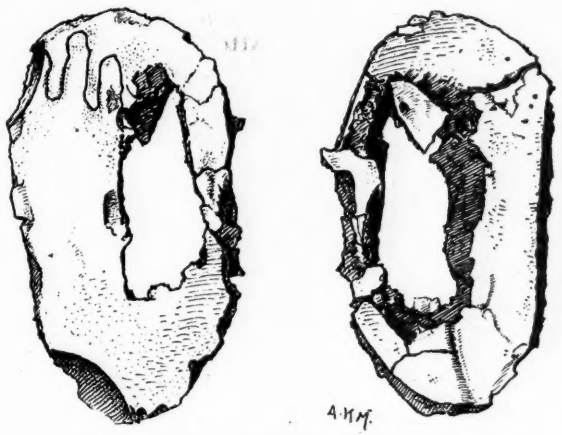
Wound.—Transverse gutter wound, 6 cm., over parieto-occipital suture, crossing mid-line, slightly more to the left. Cerebral substance extruding. *X*-ray report: "Fracture with indriven bone fragments, together with small pieces of metallic dust."

FIG. 538.—*Case* 37. Wounds before evacuation, fifth day.

Neurological Findings.—A low grade of choked disc. Unable to recognize objects, though vision not entirely lost; "things look hazy" to him. Some weakness of right arm and leg, without sensory impairment. Deep reflexes bilaterally + +, with ankle clonus. Equivocal plantar reflexes.

Aug. 17.—Resuscitation ward during night; wound meanwhile Carrelized; became dull, vomited several times, and would no longer co-operate.

Operation, 9 a.m. (28 hours).—Novocain. Excision of dirty scalp wound, with outlining of plastic flap for closure. Block trepanation encircling depressed area (*Figs.* 539, 540). On elevating bone disc momentary sharp bleeding occurred from sinus; promptly checked with lateral clips. Tear in dura, with protruding fungus. Dura incised to margins of bone opening. Thorough irrigation of pulped and hæmorrhagic cavity in left parieto-occipital lobe; removal of innumerable small fragments of bone, many of which came away in the eye of the catheter. Defect covered by sliding flap, leaving small denuded area at side with lateral drainage.



FIGS. 539, 540.—*Case* 38. Transverse gutter fracture at occipito-parietal suture; few bone fragments adherent to inner surface.

Post-operative Course.—Aug. 20.—Return of vision in left fields, leaving a sharply-cut right homonymous hemianopsia. The weakness of right arm and leg persists. Aug. 22.—Flap protruding, though incision itself appears without reaction. Wound partly opened and Carrelized. Temperature has remained practically normal. Aug. 27.—An infected fungus underlying the flap. Attempts to Carrelize unsuccessful. Lumbar puncture: 20 c.c. of clear fluid; culture negative. Sept. 20.—Wound slowly cleaning up. Flap holding. Comparatively little discharge. General condition excellent. Neurological symptoms unchanged; right homonymous hemianopsia; slight weakness of right side. Evacuated.

Subsequent Reports.—Dec. 7 (by letter).—At Gifford House Auxiliary Hospital for past month. Wound healed; is up and about; slight weakness of right side persists. Dec. 22, King George Hospital.—Vision normal. Has had a cap with plate made. Normal power of right side largely regained. Feb. 2, 1918, 3rd London General Hospital (by letter).—Has been advised to have a bone-graft operation, from rib, to fill small defect: does not like the idea, as he is "fed up" with hospitals, and feels well enough to get home.

This case furnishes a typical illustration of the risks of covering in a bone defect overlying a dural opening and damaged brain by the flap method. For in case the removal of the devitalized cerebral tissue and the showered bone fragments is incomplete, and trouble ensues therefrom, direct access to the area is precluded unless the flap is largely sacrificed. A faulty procedure of this kind was the cause of a number of fatalities in the series.

This case was one of the first in which the principle of suction was hit upon—due to the withdrawal of a few bone fragments in the eye of the catheter, which at the time was being used largely for irrigation purposes and as a means of detecting bone fragments without the advocated introduction of a finger.

The Fatal Cases.—As stated, there were 6 fatalities in this group, one of them frontal, the other five all occipital—in fact only two strictly occipital cases recovered. Cases 35 and 38, reported above, being classed as parieto-occipital.

The *frontal* case was hopeless from the outset, and it properly belongs to *Group VII*, as both ventricles were found at autopsy to have been opened, though this was not recognized at the operation.

Case 39.—Pte. W. J. (Serial No. 201).

Oct. 20, 1917.—Large median transverse gutter wound exposing both frontal lobes; destroying falx and longitudinal sinus. Complete loss of inhibition: noisy, jocular, uncontrollable. Attempted repair, with closure, after removal of indriven bone and checking of deep-seated bleeding. Secondary hæmorrhage on second day, with development of huge fungus. Death on seventh day; temperature 107°.

Autopsy.—Radiating lines of fracture; widespread encephalitis, meningitis, and ventriculitis; large infected fungus.

The five *occipital* cases follow, the last of them of sufficient interest to report at some length.

Case 40.—Rfm. J. H. (Serial No. 30).

Aug. 3, 1917.—Lying out twenty-four hours; multiple gassy wounds of head, back, and arms. Minute punctured wound of right occiput; indriven bone; stinking abscess of occipital lobe (culture: *B. perfringens*, staphylococci, coliform bacilli). Death third day.

Autopsy.—Generalized gas infection of brain and lumbar muscles.

Case 41.—Pte. A. W. (Serial No. 65).

Aug. 17, 1917.—Without history; irrational; neurological examination futile. Large circular occipital wound; brain extruding. Resuscitation ward twenty-four hours; condition improved; right homonymous hemianopsia demonstrated.

Operation.—Imperfect toilette; defect covered by flap. Broken-down wound with large fungus. Symptoms suggesting meningitis on tenth day: lumbar puncture: turbid fluid. Death Sept. 16 (thirtieth day).

Autopsy.—Radiating fissures from bone defect to vertex. No apparent meningitis; ventricles clear; large abscess in temporo-sphenoidal lobe.

Case 42.—Pte. C. W. (Serial No. 122).

Sept. 21, 1917.—Wounded previous day going over top; wearing helmet. Left homonymous hemianopsia. Vision greatly reduced on right. Multiple body and scalp wounds, including a very large dirty occipital gutter wound; brain extruding.

Trepanation *en bloc*; laceration of dura beside sinus; right lobe much pulped; usual toilette, but incomplete recovery of bone fragments. Large wound of back; also of shoulder. Gas infection of all wounds; fungus cerebri. Death third day; temperature 105°.

Autopsy.—Gas encephalitis; vessels full of bubbles; blebs under arachnoid; entire brain pasty and soft.

Case 43.—Pte. T. H. (Serial No. 128).

Sept. 21, 1917.—Semi-conscious. Foul gutter wound of left occipito-mastoid region. Neurological tests impossible. Marked nystagmus.

Fragmentary trepanation; removal of blocks of bone driven into lateral sinus and occipital lobe; partial closure. Wound infected (staphylococci and streptococci); lumbar puncture (pure streptococci). Death third day.

Autopsy.—Mastoiditis. Linear fractures radiating to foramen magnum and over petrous bone. Subdural clot over left hemisphere. Track containing a bone fragment not recovered passes through occipital lobe to left cerebellum, which is much contused. Septic meningitis.

The last of these five fatal occipital cases is as follows. As in the three foregoing ones, there was an incomplete treatment of the track, with retention of soiled bone fragments, which were later extruded with a developing fungus. The operation was complicated by bleeding from the sinus.

Case 44.—Pte. F. B. (Serial No. 101). **Occipital gutter wound. Bilateral contusion; central blindness. Sinus injury. Incomplete toilette of pulped cavity in right occipital lobe. Convulsions. Gas infection. Meningitis. Death.**

Admission, Sept. 14, 1917, 5 p.m.—Struck by a fragment of shell about noon; wearing helmet (*Fig.* 541). Knocked down, but not unconscious. Right side weak; has not attempted to walk. Some headache; moaning, weeping; pulse 120.

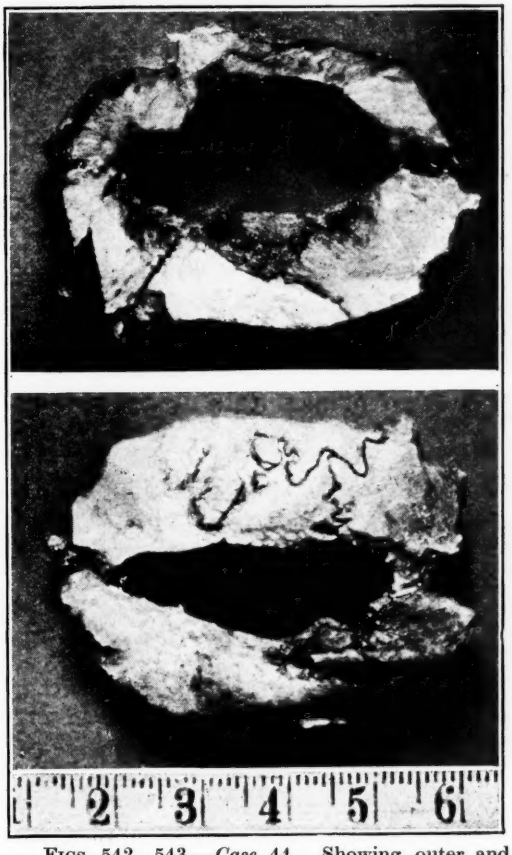
Wound.—A dirty 7-cm. transverse gutter wound crossing midline of occipital prominence. Case marked "Urgent; bleeding from sinus." Wound had been packed with gauze. *X*-ray report: "Fracture of bone, with indriven fragments."

Neurological Findings. — Central blindness; does not see flashlight. Deep reflexes active, equal.

Operation, 10 p.m. (*circa* 10 hours).—Novocain; cerebellar table. Wound excised; bone disc (*Figs.* 542, 543) encircled. On elevating disc and removing gauze plug, fresh bleeding started from sinus; checked by momentary pressure and hot saline. Laceration of the dura over right occipital lobe, with much pulping of lobe. Disorganized tissue thoroughly removed by suction and irrigation. Several bone fragments from depth of 5 cm. removed, together with pieces of stuffing of helmet. Given a drink on request: immediate vomiting, causing active bleeding afresh from sinus; bleeding controlled after some moments by placement of two muscle grafts. Owing to this complication, no further attempt made to remove remaining fragments. Partial closure of wound.

Post-operative Course. — Sept. 16.—Scalp wound shows infection. All sutures removed. Brownish pus with bubbles of gas. Lumbar puncture: 30 c.c. of bloody fluid under tension (Capt. Leitch: "Cerebrospinal fluid sterile; pus from brain, *B. perfringens*"). Sept. 18.—Wound looks better. Some return of vision. Recognizes light objects; also blue colours. Sept. 21.—A series of general convulsions yesterday and to-day. Fragments of

FIG. 541.—*Case* 44. Perforated helmet associated with occipital gutter wound.



FIGS. 542, 543.—*Case* 44. Showing outer and inner aspects of occipital gutter fracture: all fragments detached.

bone removed from track in herniating brain. Fungus increasing. Sept. 24.—Continued convulsions during past three days; increasing fungus. Sudden terminal rise in temperature (*Fig.* 544), doubtless from meningeal infection. Death.

Autopsy.—Three linear fractures radiate from defect; one extending up over vertex for 8 cm., another down into the posterior fossa to foramen magnum, the third over the right parietal bone. Extensive meningeal infection. Necrotic fungus protrudes from right occipital lobe; left lobe badly contused and pulped, though overlying dura intact. No septic thrombosis of sinus. Muscle grafts in place.

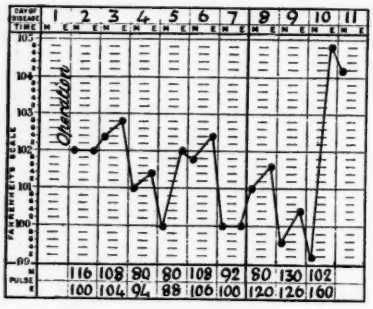

DAY OF DISEASE
1 2 3 4 5 6 7 8 9 10 11
TIME
M E M E M E M E M E M E M E M E M E M E M E
FAHRENHEIT SCALE
Operation
PULSE
116 108 90 80 108 92 80 130 102
100 104 94 88 106 100 120 120 160

FIG. 544.—*Case* 44.—Incomplete operation, with terminal meningitis.

The fatalities, as can be seen, have been due to abscess formation, meningitis, and gas encephalitis. It is regrettable that there were no opportunities to study these brains either bacteriologically or histologically, or to preserve some of them for subsequent study.

The question of an encephalitis due to the *B. Welchii* is an important one, in view of the prevailing idea that gas infection is a muscle disease. There can be little doubt as to its existence, and the subject deserves careful investigation. It is of vital importance in these cases, as in wounds elsewhere in which a foreign body with gas bacilli attached has become lodged, that all the devitalized tissue be removed together with the projectile and bone fragments, if that is a possibility. It is the reason why so much stress has been laid on the painstaking toilette of the cerebral track, as well as of the wound of the scalp and cranium, in these cases.

Fortunately, we have the promise of an effective antitoxin against *B. Welchii* infection; but though amputations for gas infections may become as rare as tracheotomies in diphtheria, and many of these disastrous gas-bacillus infections of the brain may be controlled, we nevertheless will have to employ a no less fastidious surgical technique.

Group V.—PENETRATING WOUNDS WITH PROJECTILE AS WELL AS BONE FRAGMENTS LODGED IN BRAIN.

A still more serious form of injury is one in which a missile, even though not infective in itself, has nevertheless passed through soiled coverings, with every chance of its inoculating the brain with infective material. In the cases constituting the preceding section (*Group IV*), as we have seen, despite the widely indriven bone fragments, the direct implantation of pathogenic organisms along with these fragments need not occur. However, since the brain is exposed and extrudes in both types, there is an equal risk of surface infection—possibly, indeed, greater in *Group IV*, in view of the gutter character of many of the wounds. In the presence of a lodged projectile, on the other hand, there is greater likelihood of a primary deep-seated rather than a surface infection.

In the complete series of 219 operation cases, the largest number fall in this *Group V*, for owing to the technical difficulties of the operations, and the differences of opinion regarding the proper method of conducting them, chief

attention was paid to this particular type of injury. Some, indeed, go so far as to advocate withholding operation altogether, for unquestionably many of the smaller implanted fragments are well tolerated (cf. *Case* 37, *Fig.* 537), and such local infection as may occur may be successfully overcome without operative intervention.* Indeed, in our series of unoperated cases there were several with a penetrating projectile, all of which have done well. On the other hand, these particular cases would have done equally well with a local operation, and the risks they took would have been lessened. I have come to this opinion, not only because of the numerous examples of abscess which have developed in unoperated cases sent to the base, but also because of the many instances in this particular series in which death occurred from a small abscess at the end of a track which after ten days or two weeks broke into the ventricle.

The cerebral lesions which may occur are so multiform that I see no way of making neurological subdivisions which could be of any value for our present purposes. The tracks made by the missile vary from those a few centimetres in depth to those which completely traverse the brain without emerging; or the missile may rebound from the skull and take a new course. In one brain which was studied, the projectile ricocheted twice, making three distinct tracks in different directions before it lodged. The degree of trauma produced may be promptly fatal, or negligible, depending upon many elements —the direction of the missile, its size, whether in its course it has injured a blood-vessel of any magnitude, and so on. These matters can only be touched upon here; they deserve a separate discussion.

Disregarding all other elements which affect the prognosis in penetrating injuries of this type, and confining ourselves to the hazards of infection alone, the cases, like those of the foregoing group, may be divided into two classes; (*a*) *Those in which the ventricle has escaped injury* (41 cases; 26 recoveries; mortality 36·6 per cent); (*b*) *Those in which the projectile has lodged in the ventricle or traversed it* (16 cases; no certified recoveries). Among the recovered cases in the (*a*) class, it is quite possible that there were examples of unidentified ventricular penetration; but that the condition is a serious one is evidenced by the fact that the missile was found lodged in the ventricle, or the ventricle penetrated, in more than half of the fatalities occurring in this entire group.

For the reason given in the section dealing with *Group IV*, the cases with ventricular penetration, owing to their more grave prognosis, will be detailed in a later section (*Group VI*). However, apart from the course, direction, and depth of penetration of the projectile, the factors concerned in wounds of this type are the same, whether the ventricle be involved or not. Hence, from a broad point of view, the few facts relating to all the wounds with a projectile lodged in the brain will be considered together.

There were 57 cases all told, with 31 deaths: a mortality of 54·3 per cent.

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* This is comparable to saying, as was said earlier in the war, that penetrating wounds of the abdomen sometimes recover spontaneously, therefore withhold operation in all cases. It was with great difficulty that this idea was supplanted by the view that far more cases would recover after a properly conducted operation than if left to their own salvation.

Site of Entrance.—The external wounds were cerebellar (i.e., suboccipital) in 6 cases, with 1 death (mortality 16·6 per cent); temporal in 18, with 6 deaths, all of the ventricular type (mortality 33·3 per cent); frontal in 11 cases, with 6 deaths, one ventricular (mortality 54·5 per cent); occipital in 7 cases, with 5 deaths, one of them ventricular (mortality 71·4 per cent); parietal, including wounds of the vertex, in 14 cases, with 12 deaths, six of them ventricular (mortality 85·7 per cent).

In *Group IV*, as may be recalled, there was a great predominance of parietal wounds (22 cases) over temporal ones (1 case), whereas these figures for *Group V* show a corresponding predominance of temporal wounds. Moreover, the prognosis of the temporal wounds would seem to be infinitely better, for 12 of the 26 recoveries in the series were in temporal cases—indeed all of the temporal cases, excluding the six with ventricular penetration, recovered; whereas, in contrast, out of 10 parietal cases, only 2 recovered.

The penetrating temporal and cerebellar cases, in short, appear to have a far better prognosis than do those with penetrations of the vault. It is difficult to account for this, unless one may assume that a projectile with sufficient velocity to penetrate helmet as well as skull would kill in the unprotected temporal or suboccipital regions, and that the penetrations with small projectiles so commonly seen in these regions would not occur if the parts were protected by the helmet.

Type of Wound.—With but few exceptions, all have been of the direct penetrating variety, with relatively small scalp wounds. Despite the tendency to radiating meridional fissures, the extent of which depends largely upon the size of the projectile, the physical peculiarities of the individual skull, and the anatomical seat of impact, the cranial injury, like the scalp wound, is less difficult to deal with than the large gutter wounds characterizing the preceding *Group IV*. By the external appearances alone, therefore, one may be easily misled into giving a favourable prognosis in these cases in the early hours or days after the injury.

Relation to the Helmet.—In the 21 cases from which a history could be obtained, the helmet, according to the patients' statements, was being worn in all but one instance; in one or two others it had been blown off by a shell explosion, whether before or at the moment of receiving the wound is not clear. A definite history of penetration was given in six cases, and in a few others penetration was certified by finding bits of helmet; but what is more important, in 29 the projectile was either known or, from the situation of the wound, may be supposed to have passed under the helmet.

It has been found on careful examination of the shell fragments removed at operation or autopsy, that many of them exhibit rubbed or burnished sides, edges, or angles, a condition which in all probability was produced by the passage through the helmet. This is the more likely, since the projectiles from patients not wearing their helmets, and those known to have passed underneath, do not show these smoothed surfaces. This has made it possible to correct the hearsay records of the *questionnaire*, and to state with some assurance that in 25 of the 57 cases the missile had penetrated the helmet.

Condition on Admission.—A large number of the patients (35 out of the 57) were in such a condition that no history could be elicited, and of these

35 cases 29 died. From this it would appear that only six patients, about 1 in 6, who were admitted in an unconscious or a stuporous state, with a projectile lodged in the brain, recovered after operative intervention. On the other hand, only one of the patients (*Case* 1) out of the 21 who were sufficiently conscious to give some account of themselves on admission, succumbed.

There was more than one cranial injury in 5 of the recovered cases, and in 9 of the fatal cases. There were complicating wounds elsewhere of a comparatively mild character in 2 cases, and of a severe character in 7 cases. These multiple wounds were unquestionably responsible for the fatalities in at least four instances.

The Projectile.—The missile, so far as ascertained in the 57 cases, and certified by operation or autopsy, was a shell or bomb fragment in 48, a shrapnel ball in 2, the casing of a rifle ball in 1, the fragment of a helmet in 1. The lodged fragments were single in 41 cases, multiple in 15.

The missile was removed in 22 cases, 12 of them with the magnet and nail in the manner elsewhere described. In 35 cases it was not removed: either no effort was made to extract it, owing to its small size or inaccessibility (21 cases); or the effort was abandoned, as persistence in this direction was regarded as more likely to endanger the ultimate prognosis than leaving the fragment in position.

The mortality in the 35 cases with retained missile (13 ventricular) was 60 per cent; in the 22 cases with extracted missile (4 ventricular) it was 31·8 per cent. There are of course many obvious factors affecting these results. For example, the irremovable fragments are apt to lie deeper and to have caused more damage; on the other hand, they are often very small, and well tolerated. Infection, however, plays the chief rôle in the mortality of the cases which have survived to reach the casualty clearing station. Comparatively few of the penetrating cases died early from the compression effects of the cerebral injury before the period of superimposed infection.

The size of the projectile is an important element. The largest fragment, which penetrated the helmet and lodged, weighed 46 grm., the smallest less than $\frac{1}{2}$ grm. The smaller fragments, naturally, are far more commonly seen.

One can usually tell, by comparing the missile and the cranial defect in the trepanation blocks, in just what position the projectile entered the skull; and what is perhaps less well known, one can tell by the burnished or rubbed surface of the fragment in just what position it passed through the helmet. As we shall see, some of the examples of multiple projectiles (e.g., *Case* 52, *Fig.* 559) are accounted for by the shell fragment having been split on its passage through the tough helmet.

It is regrettable that cultures were not taken in all instances, but circumstances hardly permitted of this. The impression is abroad that the foreign bodies are commonly found sterile. The several projectiles of which cultures were made by Dr. Leitch after operative removal all showed organisms of greater or less pathogenicity. It is a matter which deserves further study.

A few selected histories will illustrate some of these points. The *temporal* cases, being the most numerous, may receive first consideration. The following is an example of a trifling wound of penetration of the type which doubtless

may often recover by itself, as in *Case* 37 cited in the preceding group. The man had multiple wounds, all under the level of the helmet—one of the eyebrow, which was supposed to be the wound of entrance for the small intracranial fragment disclosed by the *x* rays. Not until the blood-encrusted scalp was shaved was the wound in the temporal region disclosed.

Case 45.—L.-Cpl. G. B. (Serial No. 43). **Multiple wounds. Minute shell fragment penetrating from right temporal region to the opposite hemisphere. Magnet extraction. Recovery.**

Admission, Aug. 11, 1917, 3.45 p.m.—Wounded while wearing helmet on morning of Aug. 10; unconscious; lying out for twenty-four hours; made his own way back to dressing station this morning. In good general condition; headache; apathy; no vomiting.

Wounds.—Multiple, of head (*Fig.* 545): (1) Severe wound of right brow of gutter type, no brain extruding; (2) Transverse tear of lower lip and chin, with loss of substance; (3) Penetrating wound over angle of jaw, with fracture; (4) Minute puncture in right temporal—not disclosed until head shaved. *X*-ray report: "Small intracranial projectile in left hemisphere."

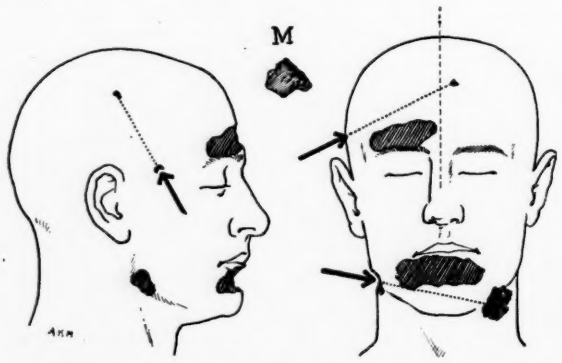


FIG. 545.—*Case* 45. Diagram to show situation of wounds: cranial penetration below helmet by 0·12-grm. missile (M) (natural size).

Operation, 5 p.m. (*circa* 36 hours).—Ether. Supposed wound of entrance over brow found to be a scalp wound; excised; closed. On pressing temporal muscle, brain substance extruded from small punctured wound; flap reflected, disclosing penetrating wound and bleeding meningeal vessel; trepanation; dura found punctured, with bleeding artery at margin; catheter enters track 10 cm; nail inserted; magnet extraction of minute 0·12-grm. missile (*Fig.* 545M); partial closure, with gutta-percha drain. Wound in jaw passes across throat, where large 12·5-grm. projectile, portion of detonator, was found lodged behind opposite angle of jaw. Lip wound loosely closed over Morison's paste.

Subsequent Notes.—Temperature normal. No untoward symptoms; perfect healing of cranial wound; others in good condition. Evacuated tenth day. No later report.

The disclosure in this case of injured meningeal and cortical vessels shows how important it may be to investigate the underlying conditions in wounds over the Sylvian area, even when the wound of penetration may seem trifling, Favourable as they have proved to be, one cannot belittle these temporal operations, however, for they are often very troublesome, owing to bleeding, which may be started afresh by the trepanation.

It is in the temporal region that one may with advantage employ flap operations, for, owing to the thickness of the muscle, proper exposure without excessive damage to the fibres may otherwise be difficult to secure. On replacing the flap, a single wick of gutta-percha tissue passed through the wound of entrance is usually all that is necessary, and excision of the scalp wound has rarely been practised.

Case 46.—Pte. J. D. (Serial No. 148). **Penetrating left temporal wound, with lodgement of two metal fragments. Direct drainage.**

Admission, Sept. 27, 1917, 4 a.m.—No history obtainable; semi-conscious; pulse 60.

Wound.—Small, penetrating, left temporal (cf. *Fig.* 546). *X* rays show metal fragment 5 cm. in temporal lobe.

Neurological Findings.—When roused, proved completely disoriented; apparent aphasia. Possible slight weakness of right face. Deep reflexes active, without clonus.

Operation, 7 p.m. (over 15 hours).—Novocain. Temporal flap reflected; penetrating wound of squamous wing enlarged, disclosing ragged tear in dura about 1 by 2 cm.; immediately a large clot with disorganized brain substance and two small unrubbed bits of shell extruded themselves (*Fig.* 546). Cavity irrigated and sucked; dichloramine-T; cigarette drain of gutta-percha through unexcised wound of entrance. Closure of flap.

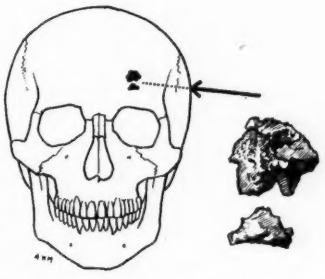


FIG. 546.—*Case* 46. Showing 1·2-grm. shell fragments (natural size), and course under helmet.

Post-operative Note.—Perfect healing; sutures removed third day (*Fig.* 547); rapid return of speech; evacuated fifth day with normal temperature.

Subsequent Reports.—Oct. 18, No. 47 General Hospital.—Speech and mental condition improved; evacuated to U.K. Jan. 18, 1918 (by letter).—"From King George Hospital to Convalescent Auxiliary Hospital, where he is at present, practically free from all symptoms." Feb. 1.—Reports quite well: some headache in stooping.

FIG. 547.—*Case* 46. Temporal flap, third day, before removal of sutures; drain in wound of entrance.

The following case shows that at times the more simple straight incision in the line of muscle fibres, as for a decompression, may be preferred to the flap exposure, if the point of penetration happens to be sufficiently near the usual line of incision for this operation. The missile in this case was somewhat larger and the damage greater than in the foregoing.

Case 47.—Pte. H. R. (Serial No. 186). **Right temporal penetration by small shell fragment. Decompression incision. Magnet extraction. Cultures made. Recovery.**

Admission, Oct. 13, 1917, 5.20 a.m.—In good condition. Wounded 6 p.m. evening before; wearing helmet. No loss of consciousness; walked a short distance; headache and vomiting; numbness of left arm.

Wound.—Penetrating variety, right temporal. *X*-ray report: "Foreign body in right temporal lobe."

Neurological Findings.—Slight left facial weakness; moderate nystagmus; otherwise no positive signs.

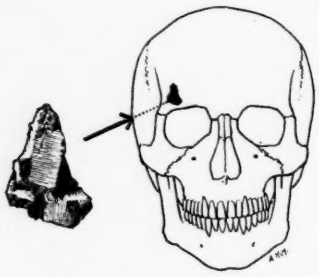


FIG. 548.—*Case* 47. Showing 2-grm. shell fragment (natural size), and course under helmet.

Operation, 12 noon (18 hours).—Novocain. Incision as for subtemporal decompression (cf. *Fig.* 549), disclosing perforation of the bone low in temporal fossa. Primary burr opening, with enlargement of defect. Much disorganized brain with clots irrigated and sucked from track, which was 5 cm. in depth. Missile (*Fig.* 548) removed by magnet on first trial. (Cultures: *B. proteus* only.) Wound closed, with direct drain.

Post-operative Course.—Uneventful; perfect wound healing (*Fig.* 549); highest temperature 99°. Evacuated ninth day.

Subsequent Reports.—Oct. 22, No. 14 General Hospital.—Condition normal; no headache. Evacuated to England. Feb. 13, 1918 (by letter).—Was kept in bed for two months owing to dizziness; drum of right ear found perforated; gets headaches if too active; in S.A. Military Hospital, Richmond.

A slightly more severe type is the following, with a wound sufficiently high and of such size as to favour a tripod incision with block trepanation. The penetration was deep enough and the damage severe enough to injure the geniculo-calcarine pathway. The square missile had punched its way through the squamous wing and carried the bone fragment with it.

FIG. 549.—*Case* 47. Subtemporal incision, third day; wound of entrance opposite pinna.

Case 48.—Pte. J. W. (Serial No. 165). **Penetrating right parieto-temporal wound: shell fragment. Contralateral palsies; homonymous hemianopsia; epilepsy. Recovery.**

Admission, Oct. 3, 1917, 5 a.m.—Wounded previous evening; shell explosion; missile went under helmet; temporary unconsciousness; tried to walk, and found left side weak.

General Condition.—Fair; pulse 68; headache.

Wound (*Fig.* 550).—Penetrating variety, 3 cm. above right pinna; brain extruding. *X*-ray report: "Fracture of squamous bone; large missile 5 cm. deep."

Neurological Findings.—Weakness of left face and arm; tongue to left; left

homonymous hemianopsia. Deep reflexes: left active, with positive Babinski; right barely elicited.

Operation, 2 p.m. (*circa* 18 hours).—Novocain. Tripod incisions; reflection of flaps, exposing fungus with bleeding vessels requiring clips, and a square punched-out window in the squamous wing. Trepanation *en bloc* (*Fig.* 551). The bone fragment corresponding with the defect lay at 3 cm. depth, and the missile beyond at 6 cm., resting on the tentorium. Attempt at magnet extraction unsuccessful; removal with duck-bill forceps of a 5-grm. piece of copper driving-band of a 4·2 shell. Toilette of cavity, with irrigation and suction; dichloramine-T; closure without drainage.

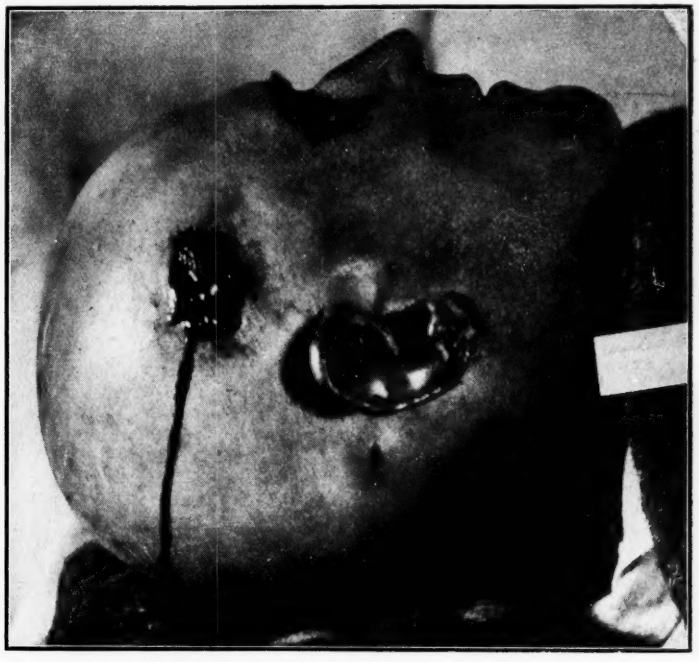


FIG. 550.—*Case* 48. Wound of entrance.

Post-operative Course.—Temperature practically normal throughout; perfect wound healing; sutures removed third day (*Fig.* 552); early clearing up of upper quadrants of hemianopic fields; three left-sided focal seizures, beginning in hand, on the sixth day; improvement in left-sided weakness; evacuated on eleventh day.

Subsequent Reports.—Oct. 22, No. 18 General Hospital.—In good condition; no alteration in symptoms; evacuated to England. Dec. 14 (by letter).—Discharged from army. "Free from all symptoms—quite well."

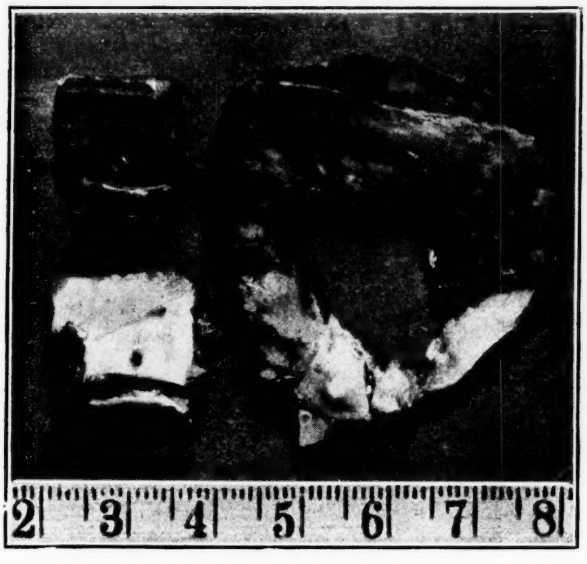


FIG. 551.—*Case* 48. Showing temporal block with 5-grm. copper missile and punched-out bone fragment (natural size).

The other seven temporal cases, all of which recovered, range from those of the above type to those with fragments driven through to the other hemisphere or to the occipital lobe. The foreign bodies range up to 6 grm. in weight

—none of them very large therefore—none showing evidence of passage through a helmet. In three the foreign body was retained, The four fatalities. as stated, all occurred in ventricular cases (cf. *Group VI*).

FIG. 552.—*Case* 48. Wound on third day.

The *cerebellar* penetrations, though few in number, were as favourable as the temporal ones, the single fatality out of the 6 cases being due to a gas encephalitis. Like the temporal cases, moreover, these are suited to a flap operation.

The history of the five that survived is very similar; two of them may be given in illustration.

Case 49.—Pte. T. T. (Serial No. 172). **Penetrating suboccipital wound. Hemilateral flap exposure of cerebellum; magnet extraction of missile; direct drain.**

Admission, Oct. 4, 1917, 10 p.m.—Wounded at 10 a.m., shell fragment passing under helmet; temporary unconsciousness; aroused, and walked back with assistance; very unsteady," as though drunk"; right leg worse than left; very dizzy; frequent vomiting. General condition good.

Wound.—Penetrating type; right sub-occipital (cf. *Fig.* 554). *X*-ray report: "Missile 4 cm. deep below mastoid process."

Neurological Findings.—Characteristic right cerebellar symptoms; vertical and lateral nystagmus, coarser to right; inco-ordination, particularly of right side, affecting both arms and legs, shown by usual tests. Deep reflexes exaggerated, without clonus; dorsal toe-response on left. Deafness in right ear.

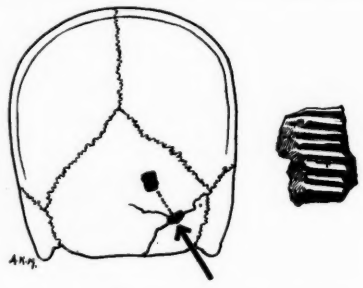


FIG. 553.—*Case* 49. Showing 1·8-grm. fragment (natural size), and course under helmet.

Operation, Oct. 5, 10 a.m. (24 hours).—Novocain; cerebellar position. Unilateral exposure by flap, disclosing sub-occipital penetration without radiating fractures; removal of bone from sub-occipital area; bone fragments, clots, disorganized cerebellum extruded from dural opening. Missile detected by catheter at depth of 5 cm.; futile attempt to catch missile in forceps; magnet extraction, on first attempt, of 1·8-grm. unrubbed shell fragment (*Fig.* 553). (Cultures gave abundant growth of an unidentified bacillus, with cocci.) Dichloramine-T. Closure of flap; direct drain through track with gutta-percha wick.

Post-operative Course.—Uneventful recovery; highest temperature 100°; sutures and drain removed third day (*Fig.* 554); healing by primary union; cerebellar symptoms much lessened. Evacuated tenth day.

Subsequent Reports.—Oct. 22, No. 11 General Hospital.—Some nystagmus, ataxia, and headache persist; also right deafness. Good condition; wounds solidly healed. Evacuated to England.

FIG. 554.—*Case* 49. Flap incisions on third day, with wound of entrance.

The following case was very similar, cultures of the fragment showing *B. Welchii.*

Case 50.—Pte. E. W. (Serial No. 189). **Penetrating shell fragment in right cerebellum. Magnet extraction. Recovery.**

Admission, Oct. 13, 1917, 2 p.m.—Was wounded 1 p.m. previous day; sitting down; wearing helmet; blown into air; unconscious; recovered, and crawled back to trench as too unsteady to walk; very dizzy; nausea but no vomiting. Good general condition.

Wound.—Small penetrating type, right sub-occipital. *X*-ray report: "Indriven bone and metal fragment."

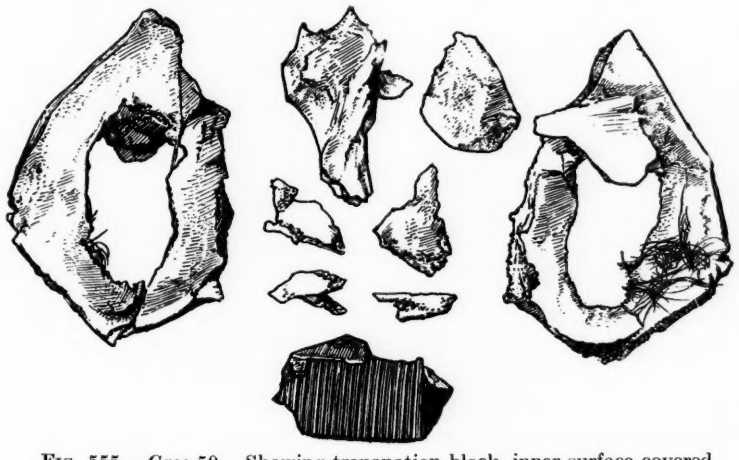


FIG. 555.—*Case* 50. Showing trepanation block, inner surface covered with hair; bone fragments and 6·3-grm. missile (natural size).

Neurological Findings.—Coarse nystagmus, more marked to left. Some static ataxia; very little inco-ordination of arms. Deep reflexes exaggerated, equal; no clonus; normal plantar responses.

Operation, 5 p.m. (28 hours).—Novocain; cerebellar table. Incisions for unilateral cerebellar flap procedure; exposure of penetration in bone and very dirty fungus, with masses of hair. Trepanation *en bloc* (*Fig.* 555) to edge of mastoid. Dural penetration just below lateral sinus, which was uninjured. Cerebellar hemisphere much disorganized; many indriven fragments of bone. Missile not detected

by catheter; extraction from bottom of cavity at 5 cm. depth, on first attempt with magnet, of a 6·3-grm. unburnished shell fragment, together with six additional pieces of indriven bone. Usual toilette of cavity; dichloramine-T. Closure of flap, with direct drain of gutta-percha introduced through unexcised wound of entrance. (Cultures of missile gave mixed organisms, *B. Welchii* predominating.)

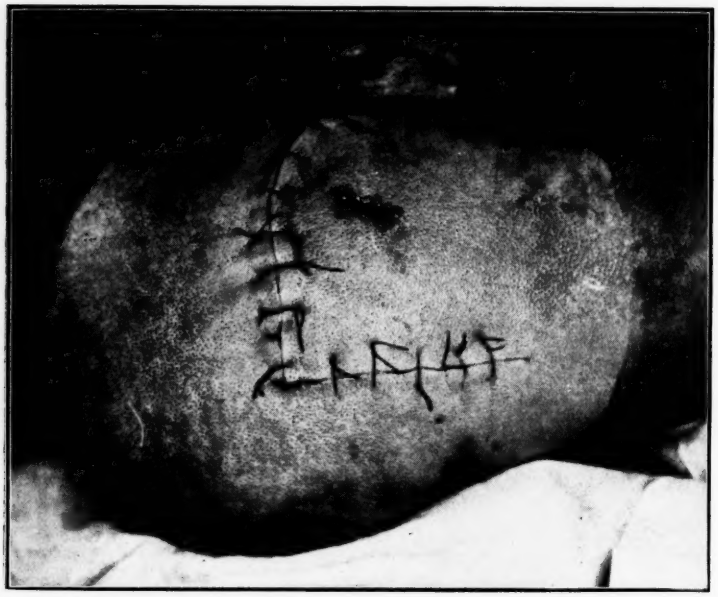


FIG. 556.—*Case* 50. Operative incision on third day, with wound of entrance.

Post-operative Course.—Uninterrupted convalescence; sutures removed third day (*Fig.* 556); perfect wound healing; highest temperature 99°; lumbar puncture fourth day owing to headache (culture sterile); lessening of neurological symptoms; evacuation eighth day.

Subsequent Reports.—Dec. 18, Suffolk Auxiliary Hospital.—Perfect recovery; discharged to command depôt. Dec. 23 (by letter from home).—Only complaint numbness of scalp owing to division of sub-occipital nerves. Feb. 20, 1918.—On duty at command depôt; in good health; some discomfort on stooping.

The single fatality among these simple cerebellar penetrations was due to a gas infection, and the outcome in the case just recorded may be regarded as fortunate, in view of the cultural findings in a wound twenty-four hours old. Of the three other cerebellar recoveries, in one the missile (5-grm. shell fragment) was removed as above; the other two had small fragments which were not extracted—one of them, a case operated upon by Captain Horrax, in which the fourth ventricle was apparently opened.

As has already been stated, the fact that the prognosis in penetrating wounds from missiles passing under the helmet is better than from those which pass through it, should not be misread as an argument against the helmet. Had the helmet sufficiently protected temporal and occipital regions, doubtless many of these penetrations would not have occurred, and wounds in these situations from missiles having a sufficient velocity to have penetrated a covering helmet would probably have caused immediate death from basilar extravasations. Conversely, the penetrations traversing the helmet, which we are now to consider, would in all likelihood have been fatal had it not been worn. The results, as we shall see, were far less good.

In the 7 *occipital* penetrations, there were only 2 recoveries. In the following example the missile, a deep-lying shrapnel ball, was not recovered.

Under the impression that it must be of lead, the magnet was not employed. As the *x* rays showed it to be undeformed, it was probably of iron, as in the case reported in *Group III.* Up to this time, however, it has been well tolerated.

Case 51.—Pte. L. W. (Serial No. 171). **Left occipital shrapnel penetration, with contralateral symptoms, including hemianopsia; missile retained. Recovery.**

Admission, Oct. 4, 1917, 5 p.m.—Wounded in early morning; unconscious; on recovery walked short distance despite weakness of right side. General condition good.

Wound.—Penetrating, mid-occipital, 3 cm. above protuberance; brain extruding. *X*-ray report: "Fracture with indriven bone and shrapnel ball near midline, about at top of tentorium" (*Fig.* 557).

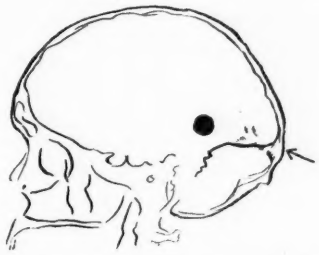


FIG. 557.—*Case* 51. Sketch from *x*-ray picture: penetrating shrapnel ball.

Neurological Findings.—Right homonymous hemianopsia, and some obscuration over left fields as well. Weakness of right arm, leg, and face, with hypæsthesia. Deep reflexes over-active; no clonus; normal plantar responses.

Operation, Oct. 5, 10 a.m. (*circa* 28 hours).—Novocain. Tripod incision encircling wound; trepanation *en bloc*; dura penetrated just to left of sinus, which was uninjured; track 8 cm. deep in left occipital lobe, sucked clean; many indriven bone fragments removed. Ball palpated with catheter; unsuccessful attempt to extract by forceps, by gravity, by change of position, and by suction through fragment of stomach-tube introduced through track; magnet not tried. Dichloramine-T. Closure with no drain.

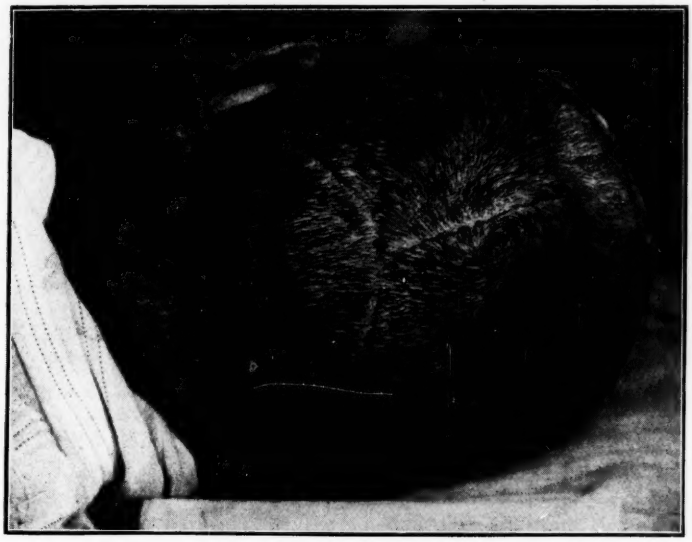


FIG. 558.—*Case* 51. Tripod incisions; sixth day.

Post-operative Course.—Temperature averaging 99° to 100°; sutures removed third day; right hemianopsia persisting, though other right-sided symptoms subsided. Perfect healing sixth day (*Fig.* 558). Evacuated tenth day.

Subsequent Reports.—Dec. 18, 4th London General Hospital.—Perfect recovery aside from right hemianopsia, complete for left eye, upper quadrant alone for right eye. Boarded out. Jan. 14, 1918 (by letter).—In best of health; but little trouble from hemianopsia; no headaches. Discharged from army Jan. 7.

A shrapnel ball is far less likely to carry in and implant infective material than is a jagged shell fragment. Prolonged, though ineffectual, efforts were nevertheless made to extract the missile, owing to an experience with an

officer who was seen in consultation six months after he had received a similar injury resulting in hemianopsia. No effort at extraction had been made at his original operation, and there seemed to be no reason for intervention when he was seen; but six months later, following an epileptiform attack, he was operated upon by another surgeon, who found and opened an abscess cavity from which the ball was removed.

Generally speaking, missiles which are of this size and weight (an iron shrapnel ball weighs 11·7 grm.) are too large to be left *in situ* without at least an effort at removal—always with the proviso that this effort must not produce further damage.

There were only 2 recoveries in the 16 *parietal* cases, one of them a simple case with a minute missile in the opposite hemisphere, which was left without effort at extraction. The other was an injury of more serious grade. This case, the first of the series, and subjected to a most imperfect operation, nevertheless, after many periods of discouragement, finally made a complete recovery.

Case 52.—Pte. R. MacL. (Serial No. 1). **Penetrating wound of right post parietal region. Massive fracture of skull. Cerebral herniation; multiple foreign bodies, one of which caused an abscess. Ultimate recovery, with hemianopsia.**

Admission, July 23, 1917.—No history obtainable (missile had penetrated helmet).

Condition.—Restless; stuporous, but can be roused; pulse 60, later rising to 120.

Wounds.—(1) Small, penetrating type, in left temporal region; (2) Large dirty lacerated wound to right of mid-line over lambda, with extensive escape of disorganized brain matter and widespread radiating fissures, so that crepitus could be felt almost anywhere over left side of head. Marked dilatation of extracranial vessels; extravasation of blood and cerebrospinal fluid under scalp over entire head. *X*-ray report (*Fig.* 559): "Two metal fragments, right side of head, temporal region. Penetration of occiput, with extensive fractures; indriven bone."

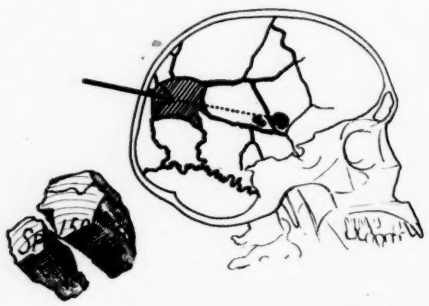


FIG. 559.—*Case* 52. Drawing of shell fragments, split in two (natural size); also position of lodgement in brain, taken from *x*-ray picture, with lines of fracture.

Neurological Findings. — Fundi show vitreous hæmorrhages obscuring disc on left; papillœdema on right; apparently complete loss of central vision. Apparent weakness of left arm. Deep reflexes hyperactive, without clonus. Normal plantar, absent cremasteric and abdominal reflexes. Possible uncinate lesion: when roused, complains of vile taste and smell.

Operation (hours not recorded).—Ether. (1) Left temporal wound excised; a few pieces of indriven bone puncturing dura removed; (2) Parieto-occipital wound excised; no treatment of track in greatly disorganized brain beyond removal of a few superficial fragments of bone; missile not recovered. Incomplete closure; drainage.

A stormy convalescence: infected wound; cerebral hernia; attempted Carrelization of wound; symptoms of abscess, presumably around retained missiles, which stereo *x*-ray plates show in temporal lobe.

Second Operation, July 30.—Ether. Vertical incision for subtemporal decompression; trepanation and opening of dura; large abscess located deep in lobe (cultures: diplococci and coliform bacilli); magnet extraction of two fragments (*Fig.* 559) from nose of shell—evidently one 7·2-grm. fragment split in two by

passage through helmet, as one surface is highly smoothed and burnished (cf. *Fig.* 562).

At the time, some fragments of bone were removed from the fungus in the posterior wound (cultures : diplococci and *B. Welchii* in abundance). Attempts to Carrelize wounds were persisted in ; sudden rise in temperature on Aug. 3 (12th day) to 105°, with nystagmus, profuse sweating, involuntaries, vomiting, and collapse, which followed an irrigation in the ward ; other upsets of the same kind occurred on the 19th and 31st days (*Fig.* 560).

To shorten the story : the temporal abscess healed perfectly, but the trouble from the incompletely treated track kept up for weeks, with occasional discharge

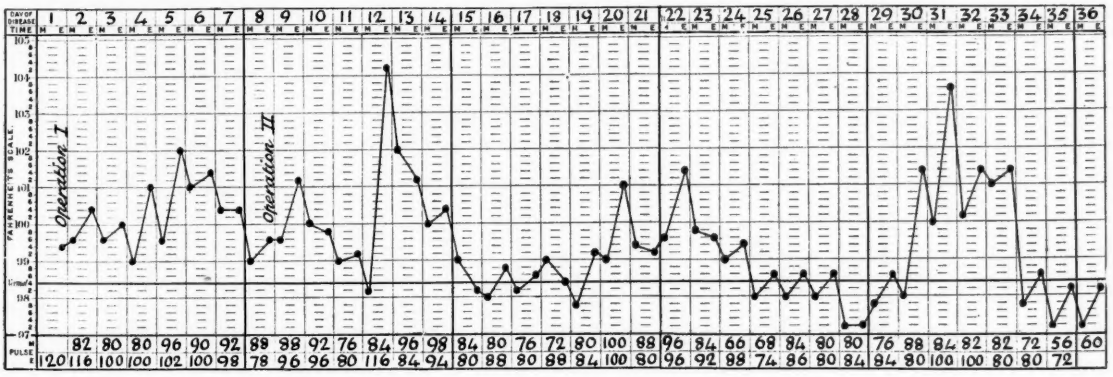
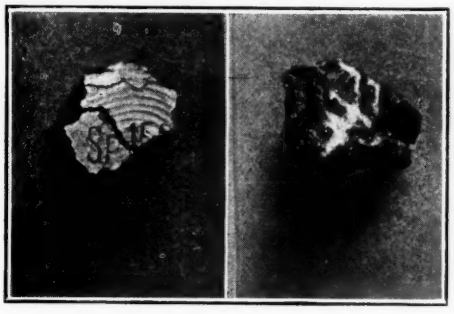


FIG. 560.—*Case* 52. Portion of temperature chart.

of fragments of bone. By September dichloramine-T was used in the wound, and gradually complete healing took place. Sept. 30 (70th day).—Evacuated in excellent condition ; wounds healed ; persisting left homonymous hemianopsia.

Subsequent Reports.—Many, from attending officers and patient.—Boarded out from Northampton War Hosp., Dec. 17. Discharged from army three weeks later. The hemianopsia has been partly recovered from and the fields have widened, though vision to the left remains imperfect ; barring this, he regards himself as a normal healthy man ; has received his discharge and returned to his occupation ; no headaches whatever.



FIGS. 561, 562.—*Case* 52. Two fragments put together, showing : *Left.*—Unrubbed surface ; *Right.*—Surface burnished by helmet penetration.

It has been difficult to do justice to the complicated story of this unexpected recovery after a sadly imperfect original operation for a serious lesion. A stormy post-operative period of this sort was, alas, too common among the cases treated in the early weeks of the service, though usually with a less happy outcome. There were many points of unusual interest which space forbids touching upon. Attention may be drawn to the abscess which formed around the retained missile, and to the split missile itself, which showed by its rubbed surface that it had penetrated the man's helmet (*Figs.* 561, 562).

Out of 12 cases with *frontal* penetration, 7 died, four of them in the group

with ventricular involvement. There is nothing particularly noteworthy about the 5 cases that recovered. All but one were examples of a small fragment or fragments deeply penetrating and not extracted: (1st) orbit to mid-brain; (2nd) multiple small scattered fragments; (3rd and 4th) crossing through falx and lying deep in the opposite hemisphere; (5th) traversing to occipital lobe. The operation in each was restricted to a small trepanation *en bloc*, with removal of bone fragments, toilette of the track, and closure of the wound. Frontal cases, as we shall see, of an entirely different order from these, are common among the fatal cases in this and also in a later section (*Group VIII*).

The Fatal Cases.—The single fatality in the 6 *cerebellar* cases occurred as follows.

Case 53.—Rfm. J. V. (Serial No. 47).

Aug. 12, 1917.—Semi-conscious; severe multiple wounds of arm and thigh. Penetration of skull behind left mastoid, under helmet; brain extruding. *X* rays show large foreign body about at vermis of cerebellum. Ataxia and nystagmus.

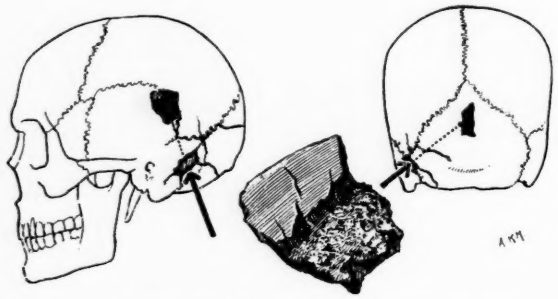


FIG. 563.—*Case* 53. Missile, 7-grm. (natural size), situation according to *x*-ray plates.

Usual cerebellar exposure (cf. *Fig.* 556). Catheter enters track to depth of 4 in. Magnet extraction of foul-smelling 7-grm. missile (*Fig.* 563), on first trial. Imperfect toilette of track. Closure, with gutta-percha drain through track. Patient restless, requiring morphia. Death, 24 hours.

Extensive gas infection, spreading through entire brain, with evidences of widespread cerebellar contusion.

A shell fragment of this size demands removal, and is almost certain to implant infective material. The case was operated upon before we came to adopt a satisfactory method for track cleansing.

The 4 fatal *temporal* cases all fall in the ventricular group, and will be described in the following section.

Brief notes of the 4 fatalities from *occipital* wounds follow, all of them, like *Case* 53, associated with sepsis arising from a soiled and incompletely cleaned track. The first was a case early in the series, with an inadequate toilette of the disorganized brain, and with the common sequel—an abscess about the foreign body, minute though it was.

Case 54.—L.-Cpl. C. L. (Serial No. 20).

Aug. 2, 1917.—Multiple wounds of scalp and extremities; penetrating wound of left occiput, brain extruding. Pulse 130. No *x*-ray examination. Aphasia.

Operation (*circa* 12 hours).—Excision of scalp wound and bone area; closure, with small drain.

Aug. 4.—Wounds infected. Carrel-Dakin treatment. Aug. 5.—Meningitis, and death the following day.

Autopsy.—Leptomeningitis. Gas abscess in occipital lobe, with infected track

leading to opposite cuneus, where lay a minute 0·1-grm. projectile of undetermined nature (? helmet) (*Fig.* 564).

Another fairly early and imperfectly treated occipital case, resulting in a spreading encephalitis, follows.

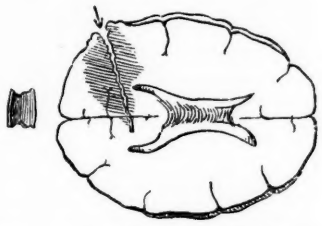


FIG. 564.—*Case* 54. Showing 0·1-grm. fragment (natural size), and its track.

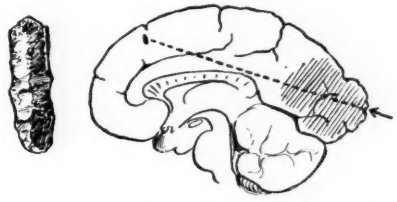


FIG. 565.—*Case* 55. Showing 3-grm. fragment (natural size), and its path.

Case 55.—Rfm. J. W. (Serial No. 51).

Aug. 14, 1917.—Case lying out 48 hours. Penetrating wound of mid-occipital region; brain extruding. *X*-ray report: "Extensive linear fractures of occiput; projectile near mid-line of parieto-frontal region. Complete central blindness."

Operation.—Novocain. Closure by flap plastic, after excision of fungus and partial cleansing by irrigation of disorganized right occipital lobe.

Aug. 19.—Apparently doing well. No especial elevation of temperature. Vision to right has returned. Wound bulging slightly: opened, with escape of stinking cerebral substance, gas bubbles, and bone fragments. Carrel-Dakin treatment. Aug. 20.—An enormous fungus, largely blood-clot with bleeding surface, has developed. Aug. 24.—Death.

Autopsy.—Entire right occipital lobe a disintegrating mass of softened brain, almost abscess-like in its consistency. The track traverses the hemisphere, and the missile, a 3-grm. shell fragment with rubbed surface (*Fig.* 565), is found near the falx in the frontal lobe.

In the next fatality, death was likewise due to infection from a track in which soiled bone fragments remained.

Case 56.—Pte. E. G. B. (Serial No. 196).

Oct. 20, 1917.—H. E. shell-fragment, penetrating helmet; entered right occiput. Brain extruding. Left homonymous hemianopsia.

Operation (12 hours).—Novocain. Gutter wound, occipito-parietal suture (*Figs.* 566–568), with two tracks: one inward toward the falx, with many fragments of bone, at 5 cm. depth; four fragments removed (cultures: streptococci). Another track directly forward for 7 cm., and 4-grm. projectile (*Fig.* 567) removed from depth by magnet (culture: *B. perfringens*). Dichloramine-T. Closure without drain.

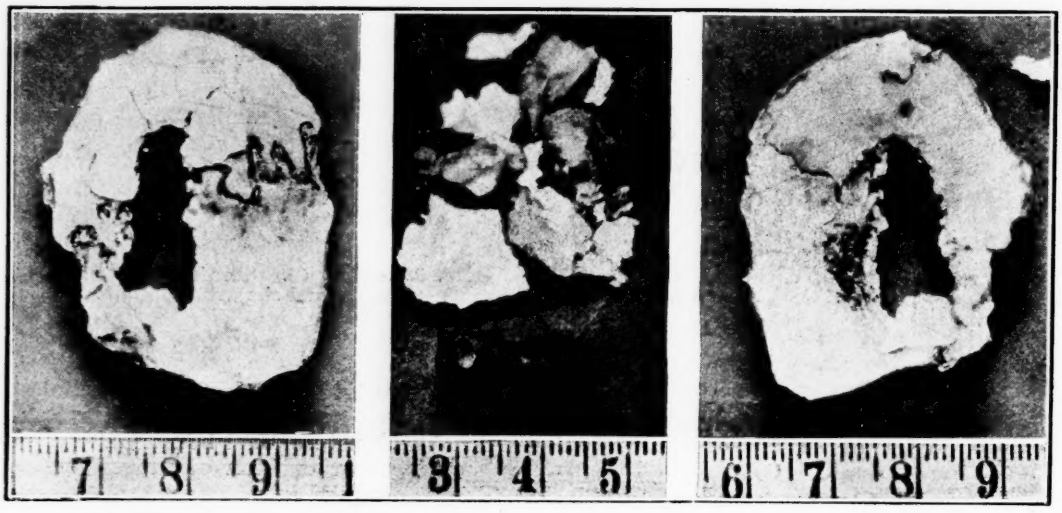
Oct. 21.—Wound re-opened; acute cerebritis. Track suction, with recovery of additional bone fragments (streptococci on culture). Drainage. Fungus cerebri. Death, 7th day.

Autopsy.—Streptococcus meningitis; sinus thrombosis; ventriculitis. Track of missile communicates with infected ventricle—probably recent communication.

The last of these four fatal cases appeared to be on the road to recovery, after a mild local infection, when an acute tetanus ended the story. In addition to his occipital penetration, there was a cervical wound which had severed his sternomastoid muscle with the spinal accessory nerve and lower branch of the facial.

Case 57.—Pte. A. F. (Serial No. 194).

Sept. 19, 1917.—Multiple wounds of neck, arm, and leg, with penetrating wound of left occiput. Unconscious ; no demonstrable local symptoms ; two foreign bodies, one supposed to be shrapnel ball.



FIGS. 566, 567, 568.—*Case* 56. Showing outer and inner aspect of bone disc at occipito-parietal suture, with rubbed 4-grm. missile and bone fragments (natural size).

Operation (after 17 hours).—Novocain. Sargent's flap procedure. Entry under helmet (?) of heavy 18-grm. missile (*Fig.* 569) just above lateral sinus ; the F.B. found lying high on tentorium, and extracted ; usual wound toilette, with closure of opening in galea and lateral drains.

Sept. 21.—Wound infected, necessitating re-opening on second day (*B. perfringens*). Suction treatment ; dichloramine-T. Temperature 104°. Lumbar puncture :

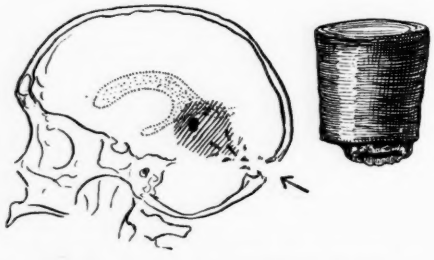


FIG. 569.—*Case* 57. Showing projectile (natural size), and course.

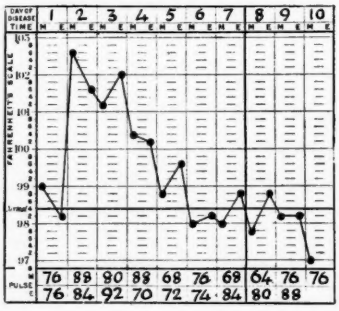


FIG. 570. Temperature chart of *Case* 57.

fluid normal ; no growth on cultures. Sept. 25.—Temperature normal ; wound cleaning rapidly. Sept. 29.—Temperature continues normal (*Fig.* 570), but there is some stiffness of jaws, increasing rapidly during day, despite intrathecal antitoxic serum ; trismus ; opisthotonos ; tetanic convulsions. Death from respiratory paralysis in 12 hours.

Autopsy.—Track of missile found communicating with posterior horn of left ventricle, which was full of thick pus.

Judging from his satisfactory general condition and normal temperature (cf. *Fig.* 570), this patient was thought to be out of danger as regards his wound infection, so that the post-mortem disclosure of an infected ventricle was a great surprise. No cultures were taken, and the pus may have been sterile. He had received an initial injection of 750 units of antitoxic serum, and no second injection had been given. Death was unmistakably due to tetanus of the acute bulbar type, possibly from an entry of toxin by way of the divided seventh and ninth cranial nerves in the deep cervical wound.

As stated, the cases with *parietal* penetration showed by far the highest mortality, for even excluding the six ventricular cases, there were 8 deaths, with only 2 recoveries. One of the fatal cases (Serial No. 7) was cited in the introductory note as an example of the early surgical failures: for only three of the first ten cases in the series with dural penetration recovered, and five fatal parietal cases occurred in the first two weeks of the service, before our technical measures had been perfected. This element must be taken into consideration in pointing out the supposed unfavourability of these parietal penetrations.

The first case died from hæmorrhage around the brain stem, as follows.

Case 58.—Sgt. J. C. (Serial No. 8).

July 29, 1917.—Unconscious, with actively bleeding left posterior parietal penetration.

Operation.—Bleeding vessel on cortex clipped. Respiratory failure four hours later.

Autopsy.—A 6·5-grm. shell fragment with burnished corners had penetrated the pons and cerebellum, and lay in the opposite posterior fossa, where extensive hæmorrhage had occurred (*Fig.* 571).

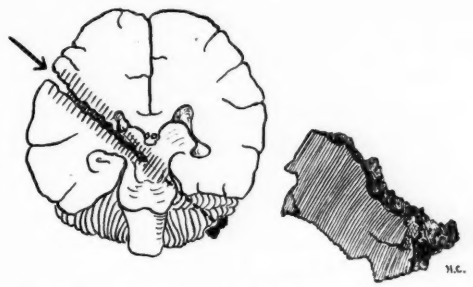


FIG. 571.—*Case* 58. Showing projectile (natural size), and course.

The next case is more typical of these older histories. It is one of the four in the entire series that died after evacuation. The man was sent down doing well after three weeks, but with a small fungus, and died in England three months later.

FIG. 572.—*Case* 59. 3-grm. projectile with polished edge (natural size).

Case 59.—Pte. E. F. (Serial No. 23).

Aug. 1, 1917.—Left mid-Rolandic penetration by shell fragment: brain extruding. Lying out 30 hours. Stuporous; right hemiplegia and aphasia, with facial epilepsy.

Operation.—Incomplete cleansing of track, though small 3-grm. projectile was removed (*Fig.* 572). Closure. Wound opened third day owing to sepsis. Eusol irrigation.

Evacuated 21st day in good condition, with small clean healing fungus. Secondary operation in England for abscess, followed by meningitis and death on Oct. 30.

We come to another familiar sequel of an imperfectly treated case—namely, rupture of an abscess into the ventricle.

Case 60.—Pte. J. S. (Serial No. 26).

Aug. 1, 1917.—Ragged wound of entry, left fronto-parietal region, with multiple wounds of shoulder and leg. *X* rays show two fragments deep in brain. Aphasia.

Operation (24 hours).—Incomplete toilette of pulped brain; superficial missile removed. Closure.

Condition excellent for two weeks; external wound healed per primam. About to be evacuated. Aug. 16.—Sudden upset, with headaches, slow pulse, choked disc, dilated pupils; temperature remains normal. Wound re-opened, and two pieces of bone recovered from track (cultures show pneumococcus). Death in 24 hours (15th day).

Autopsy.—Abscess containing small 0·7-grm. shell fragment and one bone fragment (*Fig.* 573), with rupture into ventricle. No leptomeningitis. Missile showed burnished surface.

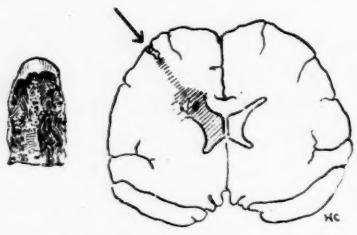


FIG. 573.—*Case* 60. 0·7-grm. projectile (natural size), with abscess rupturing into ventricle.

Another example from early in the series with insufficient wound treatment follows.

Case 61.—L.-Cpl. W. I. (Serial No. 33).

Aug. 3, 1917.—Lying-out case; maggoty wounds over left upper Rolandic area; brain extruding. Right hemiplegia. *X* rays show two defects in vault, and missile in left temporal lobe, near base of skull.

Operation.—Wounds excised; some bone fragments removed from brain; track irrigated. Flap closure.

Wound sepsis, with fungus difficult to treat under flap; eusol dressings. Death 6th day.

Autopsy.—General basilar meningitis. Track through the left hemisphere to temporal lobe; a 1·9-grm. missile (*Fig.* 574) lying free in temporal fossa (small shell fragment with highly burnished surface and angles).

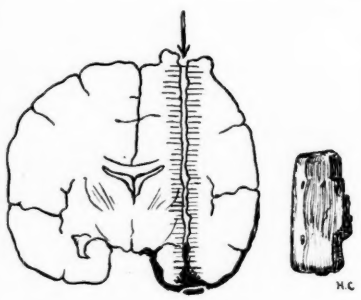


FIG. 574.—*Case* 61. 1·9-grm. projectile (natural size), traversing hemisphere.

The following shows how a very severe trauma with an apoplectic effect may be produced by a very minute fragment of shell.

Case 62.—Pte. G. W. J. (Serial No. 110).

Sept. 9, 1917.—Deeply unconscious; pulse 112; penetration in the left lower parietal region. *X* rays show F.B. on opposite side near skull.

Operation (24 hours).—Novocain. Thorough toilette, and removal of many large clots from track in left hemisphere down to falx, which blocks catheter.

Consciousness not regained; marked rise in temperature. Lumbar puncture: bloody fluid, sterile on culture. Death after 48 hours.

Autopsy.—Track from left precentral gyrus across brain, grazing falx, to right angular gyrus, where small 0·4-grm. shell fragment (*Fig.* 575) lies 1 cm. from surface. Extensive clot from injured vessels in great fissure fills track in right hemisphere. Ventricles free. No meningitis. Extensive thrombosis of sinuses.

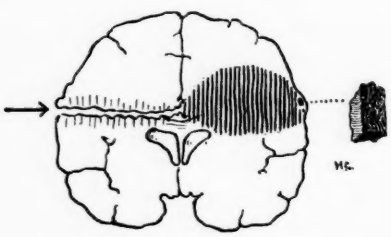
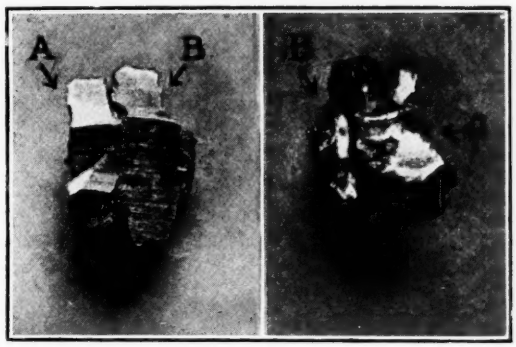


FIG. 575.—*Case* 62. Extensive damage from small 0·4-grm. missile in course through brain.

A bilateral operation should doubtless have been performed, with removal of the large clot and treatment of the track in the right hemisphere as had been done in the left.

In the next case, a left parietal penetration, the chief interest lies in the behaviour of the projectile, which proves to have been a shell fragment of 7 grm. which penetrated the helmet and split into three fragments (cf. *Case* 52); two of them were deflected into the left temporal fossa without cranial injury; the third, a 1·5-grm. piece, traversed the entire brain and lay in the posterior cerebellar fossa. This fragment was not burnished, whereas the other two had a smoothly-rubbed surface evidencing a helmet penetration. Not until it was observed that the fragments fitted perfectly together was this explained, for the bit which traversed the cerebrum constituted the side of the original piece away from the surface of impaction (cf. *Figs.* 576, 577, 578).



FIGS. 576, 577.—*Case* 63. Showing (slightly enlarged) three fragments A, B, and C (cf. *Fig.* 578), fitted together as in original missile. *Fig.* 576. —Unburnished surface with penetrating fragment A; *Fig.* 577.—Burnished surface.

Case 63.—Pte. B. B. (Serial No. 161).

Sept. 30, 1917.—Deeply unconscious. Two cranial wounds: one, severe gutter type of left temporal region; the other, penetrating type of right parietal. *X* rays show one missile in posterior fossa of skull, and two fragments supposedly in the temporal lobe.

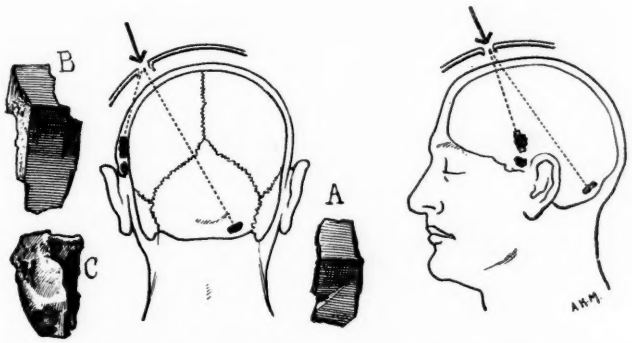


FIG. 578.—*Case* 63.—Showing three missiles (natural size), and course through helmet (cf. *Figs.* 576 and 577).

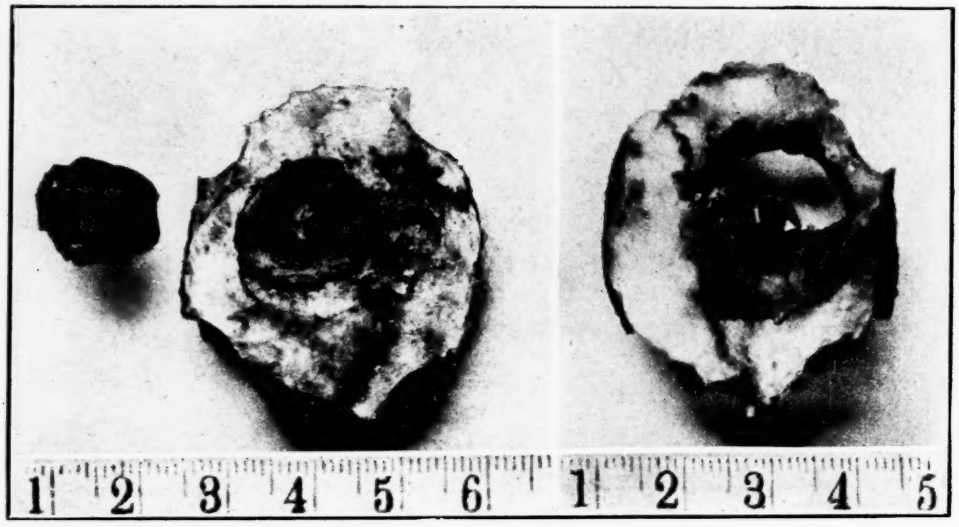
Operation.—Temporal wound proved superficial: no fracture; two fragments (5·5 grm.) removed from deep in temporal fossa. Penetrating wound drained; no attempt at missile extraction; dichloramine-T.

Post-operative Course.—Epilepsy; wound opened 4th day; cultures sterile. Very little improvement in condition. Death on 6th day.

Autopsy.—Extensive subdural clots over right cerebral hemisphere and in cerebellar fossa. Track passes (*Fig.* 578) through tentorium to cerebellum, where a 1·5-grm. fragment of the original missile lies in a clot near lower surface of lobe. No meningitis.

One may be very much deluded by the apparent well-being of a patient and by the excellent appearance of the outer wound, and so regard the case

as a suitable one for evacuation. The explosion may either be sudden or with some warning. In the following case the warning rise in temperature



FIGS. 579, 580. *Case* 64. Trephine block over occipito-parietal suture; 3-grm. missile removed by magnet at later session.

due to an abscess from a retained missile passed unnoticed, and the wound was re-opened too late.

FIG. 581.—*Case* 64. Wound on second day (cf. *Fig.* 582).

It is this sort of experience which, to my thinking, has given the bad reputation to transportation in the ambulance trains. Complications of this kind cannot be attributed to transportation, for they occur only too often with the patient resting quietly in a hospital bed.

Case 64.—Pte. W. O. (Serial No. 170).

Oct. 4, 1917.—Unconscious; no history obtained. Penetrating wound of right parietal, with missile 5 cm. deep. Apparent left hemiplegia.

Operation (after 15 hours).—Tripod incisions; trepanation *en bloc* (*Figs.* 579, 580). Large blood-clot, disorganized brain, and bone fragments evacuated. Missile retained.

Post-operative Course.—Good recovery; consciousness regained on 3rd day; left hemiplegia revealed; perfect wound healing (*Figs.* 581, 582). Temperature normal till 9th day, when a slight rise (*Fig.* 583). Abscess suspected: wound re-opened: softened brain (cultures: *B. proteus*); cavity communicating with ventricle. A 3-grm. shell fragment removed by magnet (culture gives filamentous organism in chains). Dichloramine-T. Death 12th day.

Autopsy.—Local abscess insufficiently drained.

FIG. 582.—*Case* 64. Perfectly healed external wound on fifth day.

The two fatal *frontal* cases follow. The first is the only case in the group which definitely died from pneumonia, a fact the more remarkable in view of the respiratory difficulties so often present, and the amount of exposure so often endured. This, in general, speaks well for the routine adoption of local anæsthesia; but, even so, it is important to warn sisters and orderlies against efforts to force fluids on conscious or semi-conscious patients.

Case 65.—Sgt. McC. (Serial No. 53).

Aug 16, 1917.—Profoundly unconscious; shock; pulse 90. Penetrating wound of left frontal; brain extruding. *X* rays show fragments of distorted lead shrapnel ball. Choked disc; right hemiplegia.

Operation (15 hours).—Trepanation *en bloc*. Evacuation of large clot from lobe, and removal, from depth of cavity, of distorted shrapnel ball and several fragments of inner table. Closure.

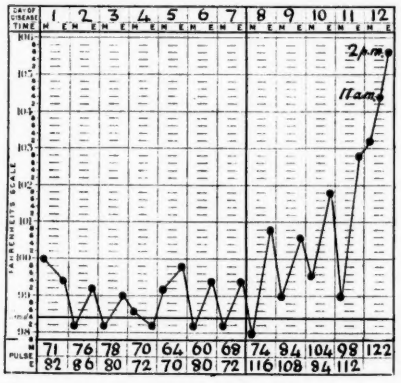


FIG. 583.—Temperature chart of *Case* 64.

Post-operative Course.—Jacksonian fits in right face. High fever: pneumonia. Death 4th day.

Autopsy.—Considerable widespread contusion of left hemisphere; wound clean; no evidence of infection. Inhalation pneumonia.

The last of these cases was discharged from the casualty clearing station apparently in safe condition, though with a small well-granulating fungus.

Case 66.—Pte. E. W. (Serial No. 198).

Oct. 20, 1917.—Penetration of helmet; wound of right forehead; brain extruding. Good condition.

Operation.—Usual procedure; an 8·5-grm. shell fragment (*Fig.* 584), showing evidence of helmet penetration, removed with bits of bone from depth of 5 cm. in hemisphere. Closure, with gutta-percha wick.

Post-operative Course.—Wound infected, requiring re-opening and drainage (cultures: staphylococci and coliform bacilli). Fungus. Wound clean, and granulating well. Normal temperature (*Fig.* 585). Evacuated Nov. 5 (17th day).

Subsequent Report.—Nov. 18, No. 3 General Hospital.—Letter announcing death from meningitis.

FIG. 584.—*Case* 66. 8·5-grm. shell fragment (natural size).

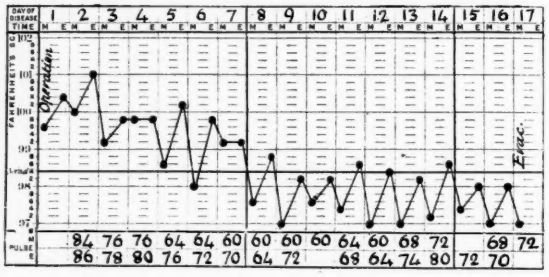


FIG. 585.—*Case* 66. Temperature irregular, tending to subnormal.

Group VI.—VENTRICULAR PENETRATION BY BONE FRAGMENTS OR PROJECTILE.

We have come to one of the most serious of complications of a penetrating wound—the opening of the ventricle or the traversing of the ventricle by the missile or by bone fragments.

Emphasis has been laid by all on the fact that the prognosis in head injuries, so far as infection is concerned, chiefly rests on whether or not the dura is intact. It has been shown, however, that minor punctures of the dura (*Group III*) are not necessarily accompanied by a bad prognosis, for, contrary to the general view, a fatal meningitis which spreads from the area of penetration is comparatively rare. Still more serious are the lesions (*Groups IV* and *V*) in which fragments, often soiled, are driven into the cerebral substance, and if not completely removed leave an infected track, with swelling and extrusion of the œdematous brain through the dural opening and external wound—the all too familiar fungus cerebri. In the course of time, either the suppurative process finds its way into the ventricle, or the advancing fungus distorts the hemisphere and draws out the ventricle, which ruptures into the infected track. Both are equally bad; examples of both sequels occurred in the series.

But far worse in their prognosis appear to be the penetrating wounds which, regardless of their point of entry, have primarily opened the ventricle, with the resultant probability of an early infection of the cerebrospinal fluid at its very source. It is for this reason that these cases have been put in a separate category. Some have gone so far as to regard them as hopeless from the outset, and have therefore eliminated them from their operation statistics. But, bad as they are, they are not entirely hopeless, as we shall see.

It is quite probable that a number of cases in *Groups IV* and *V* may have recovered with an opened ventricle, the condition not having been recognized at operation. However, with the catheter method of treating the track, it

would be hardly possible to overlook a ventricular penetration, unless all the fluid had escaped before the operation; this is improbable, for cerebrospinal-fluid leakage in a case with acute traumatic hernia cerebri is unusual.

Ventricular penetration, as already stated, has been verified at operation, or autopsy, or both, in 30 cases. The lesion had been caused by indriven bone fragments without accompanying projectile in 14 cases, of which 8 made perfect recoveries. It had been caused by the entry or passage of the projectile itself in 16 cases, with no recoveries, the condition in about half of them having been first disclosed at autopsy.

Inasmuch as the cases which have been put in this *Group VI* are, so far as the mechanism of the injury is concerned, of the two definite types considered in the preceding sections—one a tangential wound, usually parietal; the other a direct penetration, most often temporal—the facts concerning the incidents of the injuries have been assembled with the cases comprising *Groups IV* and *V* of the preceding sections.

Type A.—The Ventricle Penetrated by Bone Fragments.

We shall consider here the 14 cases of ventricular penetration by indriven bone fragments—usually, though not always (cf. *Case* 73), fragments from the inner table.

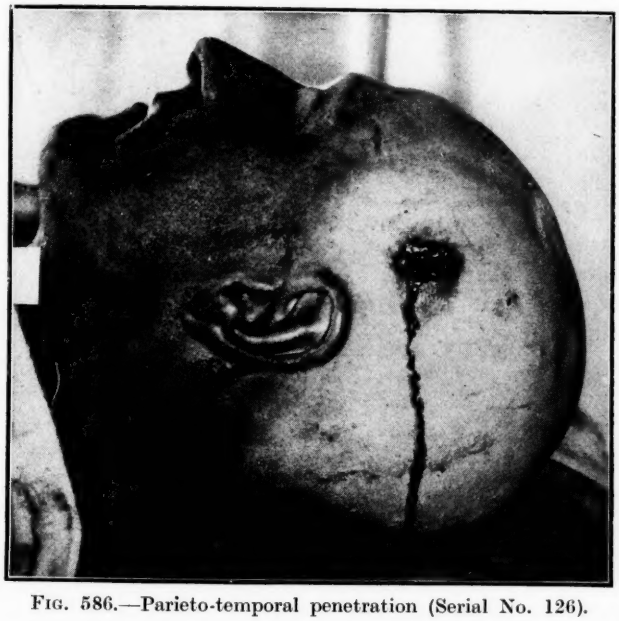


Fig. 586.—Parieto-temporal penetration (Serial No. 126).

1. The Recovered Cases.—The first two examples were of the type

Fig. 587.—4·8-grm. missile showing edges burnished by helmet.

with the foreign body lodged in the area of cranial depression. The earliest example (Serial No. 52) has no special point of interest, aside from the fact that the catheter passed along the track from the right posterior parietal region, entered the ventricle at a depth of 6 cm., and fragments of bone were removed from this depth. It was a flap operation according to Colonel Sargent's principles, and the patient has made a perfect recovery.

The second case was also of the penetrating type (Serial No. 94), with entrance in the parieto-temporal region (*Fig.* 586) the missile (*Fig.* 587) near

the surface, but with three fragments of the squamous bone indriven to the ventricle, which was emptied through the catheter in the process of cleaning the track. There were no secondary complications, and the patient has made a good recovery, with slight residual paraphasia.

The remaining cases all had wounds of gutter type, and the conditions were somewhat more difficult.

Case 67.—Sec.-Lieut. K. G. (Serial No. 106). **Frontal gutter wound, with bone fragments indriven to ventricle. Pneumococcus infection. Recovery.**

Admission, Aug. 22, 1917, 1.30 p.m.—Six hours previously had received injury from rifle ball which perforated helmet. Dazed, but managed to walk to A.D.S., where he lost consciousness.

General Condition.—Poor: stuporous, but can be roused. Resuscitation ward for 10 hours, with improvement.

FIG. 588.—*Case* 67. Characteristic *x*-ray picture showing thirteen indriven bone fragments.

FIG. 589.—*Case* 67. Bone fragments removed (cf. *Fig.* 588).

Wound.—Open, gutter type; parieto-frontal region; transverse, slightly more to right, but crossing mid-line. Brain exposed and extruding. *X*-ray report: "thirteen indriven bone fragments" (*Fig.* 588).

Neurological Findings.—Mentality apparently unimpaired (subsequently no recollection of events from time of losing consciousness till in ward after operation). Disc margins and cup obscured. No paralysis. Deep reflexes: right, normal; left, not obtained.

Operation, 11 p.m. (*circa* 18 hours).—Novocain. Excision, first, of wide gutter wound of scalp, then of bone. Exploration of sinus with soft catheter detects fragments: track leads into ventricle. Fourteen bone fragments recovered (*Fig.* 589) track cleaned; ventricle emptied; complete collapse of fungus. Partial closure by plastic flap; lateral drains. Urotropin.

Post-operative Course.—Slight rise in temperature for five days (*Fig.* 590). Cerebrospinal leak for two days, followed by dull headache. Aug. 26.—Lumbar puncture: 45 c.c. yellowish fluid under tension (culture: pneumococcus). Aug. 28.—Second lumbar puncture: 2 c.c. clear fluid, no tension (culture: a few diplococci remain). Sept. 4.—Granulating wound over the denuded area of pericranium (*Fig.* 591); the flap over defect solid and without protrusion; temperature normal. Evacuated.

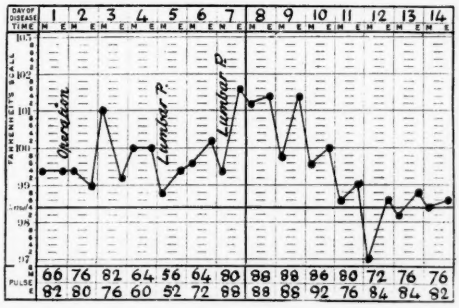

DAY OF DISEASE
1 2 3 4 5 6 7 8 9 10 11 12 13 14
TIME
A M E M A M E M A M E M A M E M A M E M A M E M A M E M A M E M A M E M A M E M A M E M A M E M A M E M
FAHRENHEIT'S SCALE
Operation
Lumbar P.
Lumbar P.
PULSE
66 76 82 64 56 64 80 88 88 86 80 72 76 76
82 80 76 60 52 72 88 88 88 92 76 84 84 82

FIG. 590. Temperature chart of *Case* 67.

Subsequent Reports.—Nov. 6 (by letter).—"Very fit in all respects; no headaches." Jan. 6 (by letter).—Given six months' leave. Occasional slight headache; general health perfect.

FIG. 591.—*Case* 67. Showing flap operation with granulating area on fourteenth day.

The recovery in this case was doubtless due to the thorough cleansing, with removal of all the disorganized brain and bone fragments; for though it was before the principle of suction came to be regularly practised, over two hours were expended on the operation, most of the time being devoted to the toilette of the track.

Another wound in the same situation and of a very similar nature (Serial No. 108), in another officer, was similarly treated at about this time by my assistant, Captain Horrax, with an equally good end-result, though the wound had to be re-opened owing to the retention of one or two fragments of bone, and in consequence a cerebrospinal-fluid leak was established which persisted for a week.

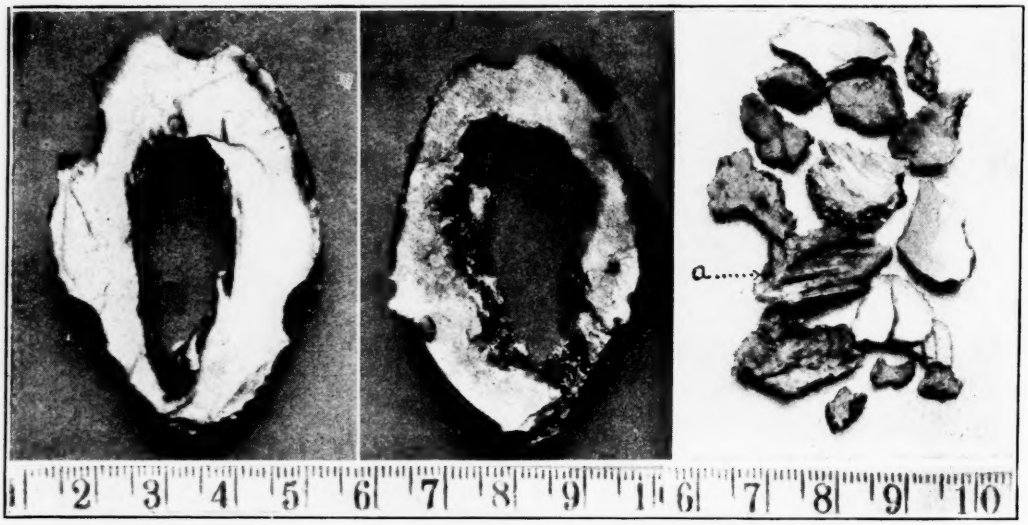
The following case is remarkable in that it was possible to make a presumptive diagnosis of ventricular penetration owing to the peculiar position of the bone fragments as shown by the stereoscopic Röntgengrams.

Case 68.—L.-Cpl. E. W. P. (Serial No. 154). **Left parieto-frontal gutter fracture, with showered fragments penetrating ventricle: some fragments, free in ventricle, retained. Recovery.**

Admission, Sept. 29, 1917, 1.40 a.m.—History of having been wounded at 7 a.m. the previous day, a fragment of shell penetrating helmet. Temporary unconsciousness. No attempt to walk. Headache. Vomiting.

General Condition.—A little hazy, but conscious and rational. Warm. Pulse 80.

Wound.—Ragged; gutter type; left parieto-frontal; longitudinally disposed; brain extruding. The *x* rays show stereoscopically a cluster of bone fragments about 7 cm. inwards from the wound of entrance, and another cluster well back in the occipital region about in the situation of the posterior horn of the left ventricle.



FIGS. 592, 593, 594.—*Case* 68. Bone disc showing gutter wound, with complete separation of fragments from inner table. Note scratching of some fragments, e.g., (*a*), of outer table by passing missile.

Neurological Findings.—Memory imperfect; orientation poor. No aphasia (right-handed). Weakness and apparent hypæsthesia over entire right side. Deep reflexes normal on left; exaggerated on right; without clonus, though with dorsal toe-response.

FIG. 595.—*Case* 68. Wound showing flap closure with small defect at angle: second day.

Operation, 2 p.m. (31 hours).—Novocain. Excision of wide gutter wound, and preparation for closure by lateral flap (cf. *Fig.* 595). Trepanation *en bloc* (*Figs.* 592, 593); no adhering fragments of inner table—all showered through dural opening, from which a large amount of clot and pulped brain was expelled by getting patient to cough. On suction of the sinus a large amount of bloody cerebrospinal fluid was withdrawn, and the mass of bone fragments was detected at a depth of 5 cm. Eight sizable fragments of both tables were picked out, and several smaller ones withdrawn in the eye of

the catheter (*Fig.* 594). Finally, a track about 2 cm. in diameter, leading from the surface to the ventricle, lay wide open. The catheter could be inserted into the ventricle a distance of 10 cm., and the cavity was irrigated with warm salt solution, but without washing out the posterior fragments (cultures taken from the ventricle grew staphylococci). About 1 c.c. of dichloramine-T was left in the track and ventricle, and the scalp was closed in layers.

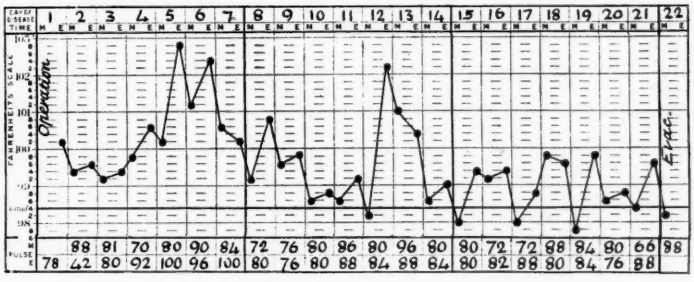


FIG. 596.—Temperature chart of *Case* 68.

Sept. 30 (*Fig.* 595).—Sutures removed. General condition unexpectedly good. Lumbar puncture: 35 c.c. slightly yellow fluid (cultures sterile). Oct. 6.—No symptoms to account for recent periods of fever (cf. chart, *Fig.* 596). Second *x*-ray examination, showing retention of deeper mass of bone in unchanged position. Oct. 19.—Complete amnesia for period between wound and operation. Otherwise no mental or other neurological abnormality observable. Evacuated.

Subsequent Reports.—Feb. 1, 1918 (by letter).—Red Cross Hospital in Chester for three weeks; thence to Cheshire Hospital. No paralysis; feels quite well aside from some "headache when he catches cold." Hopes to go before Board, get discharge, and return immediately to former occupation.

The succeeding case, though of very similar type, may also deserve recording in some detail.

Case 69.—Sgt. F. G. J. (Serial No. 160). **Right frontal gutter fracture, with fragments showered into ventricle. Usual toilette, with emptying of ventricle. Closure. Recovery.**

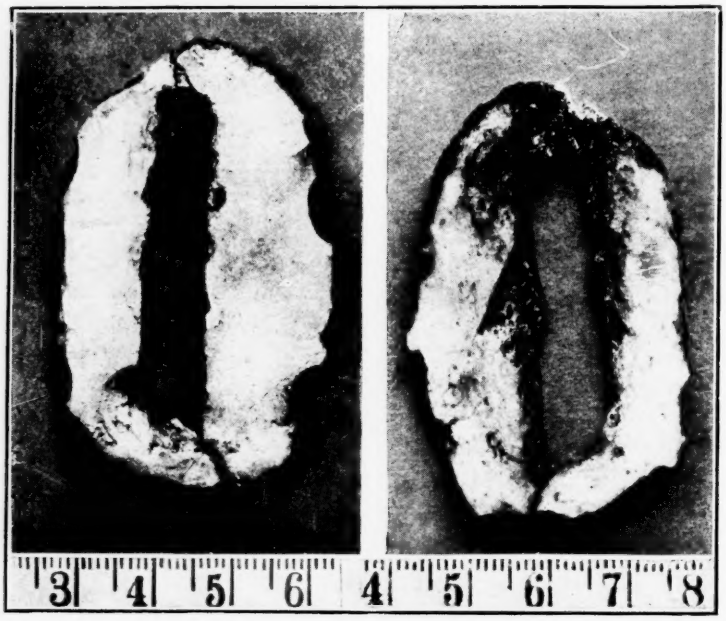
FIG. 597.—*Case* 69. Wound before operation.

Admission, Sept. 30, 1917, 2.30 a.m.—History of having been bombed during an air raid.

General Condition, 9 a.m.—Resuscitation ward during night. Conscious; fairly rational. Remembers the raid, and being without a helmet; no recollection of subsequent events. Pulse 66.

Wound.—Longitudinal gutter type, right upper frontal (*Fig.* 597); brain extruding. *X*-ray (stereoscopic) report: "Bone defect, with indriven fragments in two groups, one possibly in ventricle."

Neurological Findings.—Disoriented for time and place. Weakness of left arm and leg. Deep reflexes: brisk; equal; no clonus.



FIGS. 598, 599.—*Case* 69. Typical gutter fracture, without adherent bone fragments.

Operation, 11 a.m. (10 hours).—Novocain. Tripod ('Isle of Man') incisions encircling gutter wound. Trepanation *en bloc* (*Figs.* 598, 599). No bone fragments adherent: all indriven. Laceration of dura, 3 cm. long. Extensive pulping of lobe, with bloody fluid obviously coming from ventricle. Much disorganized brain and clot irrigated and sucked out; much more expressed during act of vomiting. Fragments palpated by catheter at depth of 5 cm.; picked out with duck-billed forceps. Collapsed brain, and wide open track communicating with ventricle. Dichloramine-T. Edges of unexcised and lacerated dural margin drawn loosely together with two fine silk sutures. Closure of scalp in layers, with no drain. Urotropin.

Oct. 1.—Some bloody and oily cerebrospinal fluid from between sutures (culture: no growth). Lumbar puncture: 20 c.c. of blood-stained fluid (culture: no growth). Temperature normal. Persistent hiccoughs; otherwise condition excellent. Oct. 2.—Temperature elevated, 101°. Lumbar puncture: 20 c.c. fluid, less blood-stained (culture sterile). Oct. 4.—Continuous hiccoughing for past two days. Temperature 103°, but no symptoms to account for it; feels well. Wound perfect: sutures removed (*Fig.* 600). Oct. 6.—Sixth day of uninterrupted hiccoughing. Says he has had similar attacks before, his mother also. Oct. 14.—

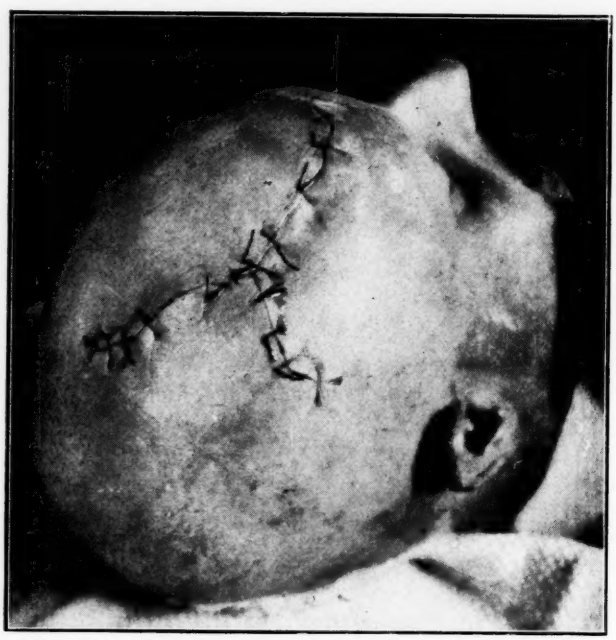


FIG. 600.—*Case* 69. Wound on fourth day (cf. *Fig.* 597).

Cessation of hiccoughs on 7th day. Normal temperature (*Fig.* 601). Condition excellent. No mental impairment. Wound solid (*Fig.* 602). Repeated *x*-ray examinations show two small fragments of bone remaining in track; none in ventricular region. Evacuated.

Subsequent Reports.—No. 11 General Hospital.—No neurological symptoms. Evacuated to England Oct. 22. Dec. 10 (by letter from King George Hosp.).—Up and about; no headaches whatever; no other symptoms so far as he can see. Feb. 20, 1918.—Has received discharge; given a skull cap with steel plate; does not know why. Expects to return to work with former firm of solicitors; thinks his memory a little defective.

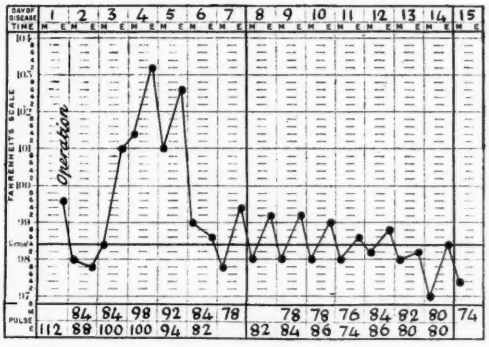


FIG. 601.—*Case* 69. Temperature chart of case with opened ventricle.

FIG. 602.—*Case* 69. Wound on twelfth day.

At times the loss of substance from the scalp is so great, or the scalp so densely adherent in the subaponeurotic layer, that a closure by plastic of the defect is most difficult or almost impossible. In ordinary cases it is simpler under these circumstances to leave the defect directly over the operative area, and permit a small fungus to develop; but in case the track communicates with the ventricle, one must close the immediate defect by some form of plastic at all hazards. The following case is an example of this.

Case 70.—Sgt. F. W. D. (Serial No. 184). **Fronto-parietal gutter wound; mild sinus syndrome; bone fragments penetrating ventricle. Recovery.**

Admission, Oct. 12, 1917.—History of having been hit about 6.30 a.m., shortly after going forward in an attack. Wearing his helmet. Stunned; found he could not walk: managed to crawl back to aid post.

General Condition.—Conscious; pulse 72; mentality unimpaired.

Wound.—Gutter type; longitudinal, 8 cm. long, just to right of mid-line at anterior parietal vertex. Brain extruding. *X*-ray report: "Fracture, with deeply indriven bone fragments."

Neurological Findings.—Complains of weakness and stiffness in legs. Moderate spasticity present, equal on the two sides. Deep reflexes brisk to exaggeration, but no clonus.

Operation, 4 p m. (10 hours).—Novocain. Excision of large greatly-soiled scalp wound, disclosing a polar opening in skull measuring 2·5 by 1·5 cm., with five meridional fissures running from it. Trepanation *en bloc*. No adherent fragments of inner table; all showered through tear in dura just to right of longitudinal sinus. Usual toilette of track; ten fragments (*Fig.* 603) of both outer and inner tables recovered from depth. On releasing largest fragment (broth culture gave staphylococci), a gush of bloody cerebrospinal fluid occurred, with complete collapse of brain, leaving track wide open. Dichloramine-T. Ragged tear in dura drawn together with two fine silk sutures. Area of defect closed with elaborate **S**-shaped plastic (cf. *Fig.* 605), leaving an area of denuded pericranium fore and aft.

FIG. 603.—*Case* 70.—Fragments removed from ventricle and track.

Post-operative Course.—Despite a superficial staphylococcus infection, the flaps held. Highest temperature 100·2° (*Fig.* 604). On second day sutures removed (*Fig.* 605). The spasticity of the legs subsided gradually, more rapidly on the left than the right. (The contused area undoubtedly present over the corresponding part of the opposite hemisphere was slower in regaining its function than the pulped area treated by suction in the right hemisphere.) The two granulating areas (*Fig.* 606) were planted with Reverdin grafts on Nov. 2. Evacuated Nov. 5.

Subsequent Report.—Nov. 30.—Evacuated to England from No. 16 General Hospital; wounds healed. Feb. 21, 1918.—Discharged from service; some dizziness and headaches.

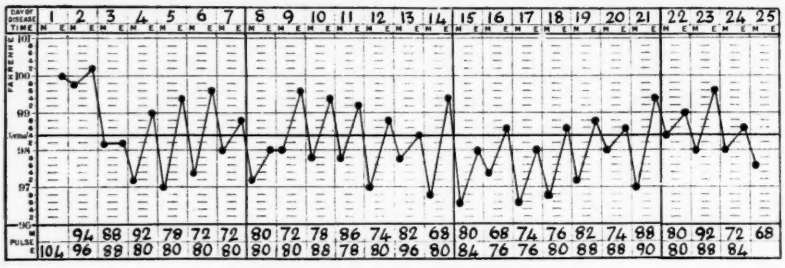


FIG. 604.—Temperature chart of *Case* 70.

The story of the last of these eight patients (Serial No. 185) with recovery after penetration of the ventricle by bone fragments, need not be recorded in full, as it is almost the counterpart of *Case* 69, except that the wound was lower in the frontal region. The patient has received his discharge from the army, and writes that he is practically free from all symptoms.

2. **The Fatal Cases.**—The first of these, the second in the operative series, shows again how imperfect were our early methods of treatment.

Case 71.—Dvr. A. A. E. (Serial No. 2).

July 25, 1917.—Patient semi-conscious; penetrating wound of upper left Rolandic region; brain extruding; superficial projectile; indriven bone. Right hemiplegia, with exaggerated reflexes.

Operation.—Ether. Excision of scalp wound and of fungus. Bone opening enlarged with rongeurs, exposing 2-cm. margin of intact dura. A few bone fragments picked out of track. Closure of defect by plastic flap, with lateral drain. Subsequent restlessness, requiring much morphia; unconsciousness; fever; death in 48 hours.

FIGS. 605, 606.—*Case* 70. Showing wound on first dressing (second day), and two weeks later.

Autopsy.—The flap of scalp covers a badly infected, stinking fungus with gas bubbles. Section of the brain exposes a softened cavity the size of an egg, containing disorganized brain and pus with bone fragments, some of which have been driven into the badly infected ventricle. Cover-glass preparations show abundant organisms of *B. Welchii* type.

Four other fatal cases with wounds of the parietal vault occurred later in the series. The first of them follows.

Case 72.—Gnr. J. G. (Serial No. 96).

Sept. 3, 1917.—Admitted in critical condition, with a cerebral herniation occupying a large parieto-frontal gutter wound involving scalp and cranium (*Fig.* 607). The skull was very rich in diploë, and there were no plates of inner table adherent to the bone disc. The detached fragments were small, and all showered. Three meridional lines of fracture radiated from the bone defect. Death on the 4th day, though the lumbar fluid was found sterile the day before.

Autopsy.—A purulent ventriculitis and encephalitis (*B. Welchii*).

The effect on the skull of these large gutter wounds, all produced by a similar form of tangential injury, varies considerably from case to case, depending greatly upon the structural characteristics of the individual calvarium. In the following, as in *Case* 34 (*Fig.* 523), the large plates of inner

table, though fully detached, remained adherent to the dura, but broke in the middle like a trap-door, and permitted the fragments of outer table to be indriven to the ventricle.

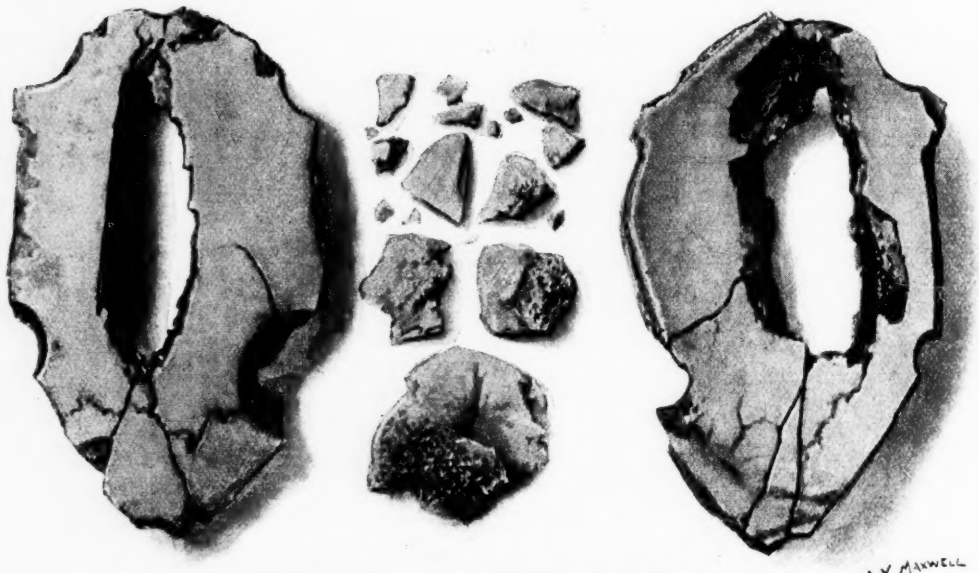
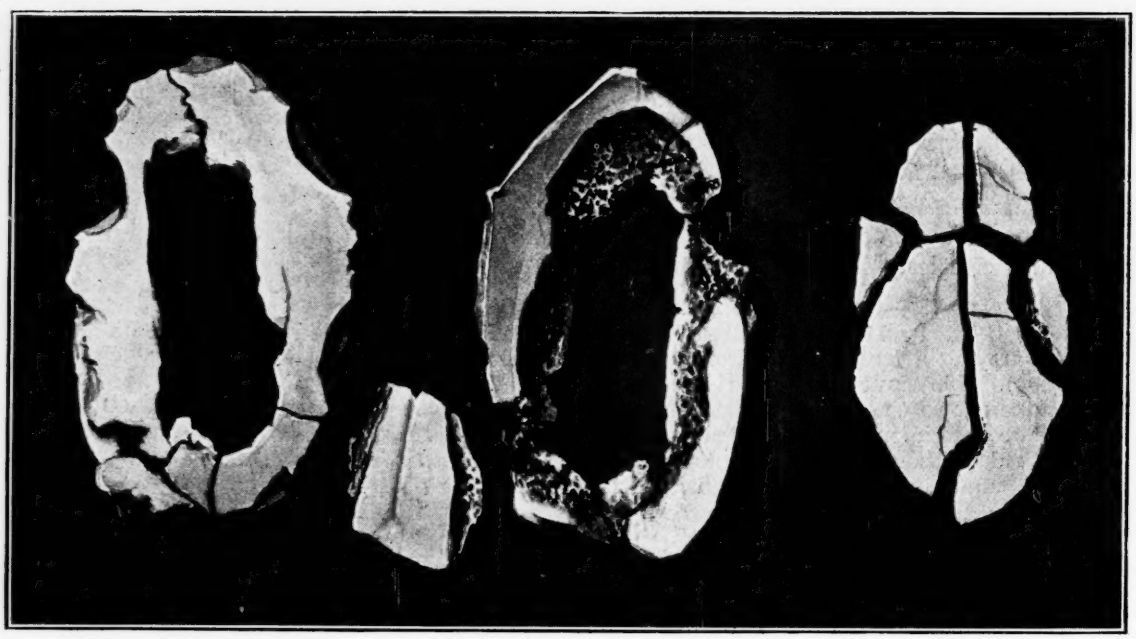


FIG. 607.—*Case* 72. Showing characteristic gutter wound from both aspects.

Case 73.—A German prisoner (Serial No. 130).

Sept. 20, 1917.—Wounded by rifle ball 48 hours before operation; not wearing his helmet. Gutter wound, right parietal; brain extruding. Left hemiplegia.



FIGS. 608, 609, 610.—*Case* 73. Outer and inner aspects of block, with fragment of external table, which was driven between the plates of inner table into ventricle.

Trepanation *en bloc* (*Figs.* 608, 609). The large leaves of broken inner table very adherent to dura (*Fig.* 610). Between them a fragment of outer table had been driven into brain, opening ventricle. Careful toilette of track. Dichloramine-T. Partial closure, with direct drainage, owing to obvious infection. Death in three days, after sudden rise in temperature to 105°.

Autopsy.—Ventriculitis; meningitis; gas infection of brain.

Another parietal fatality (Serial No. 187) was very similar to the foregoing. The man had been lying out for three days; the wound was dirty; bone fragments had been driven to the ventricle; death occurred from intracranial sepsis on the third day. The results in these delayed cases furnish the best argument for the earliest possible operation in penetrating wounds.

The following, the single occipital case in this group, is lamentable from the fact of an incomplete though early operation which failed to secure all fragments of bone. Had the man been evacuated on or about the tenth day, when doing apparently well, his upset would naturally have been attributed to the effects of transportation.

Case 74.—Pte. E. F. (Serial No. 142). **Occipital gutter wound. Ventricle penetrated. Incomplete operation. Death in two weeks from sepsis.**

Admitted Sept. 27, 1917, 3 a.m.—Wounded 6 hours before; wearing helmet. General condition fair, though drowsy and unresponsive.

Wound.—Gutter type; right parieto-occipital; brain extruding.

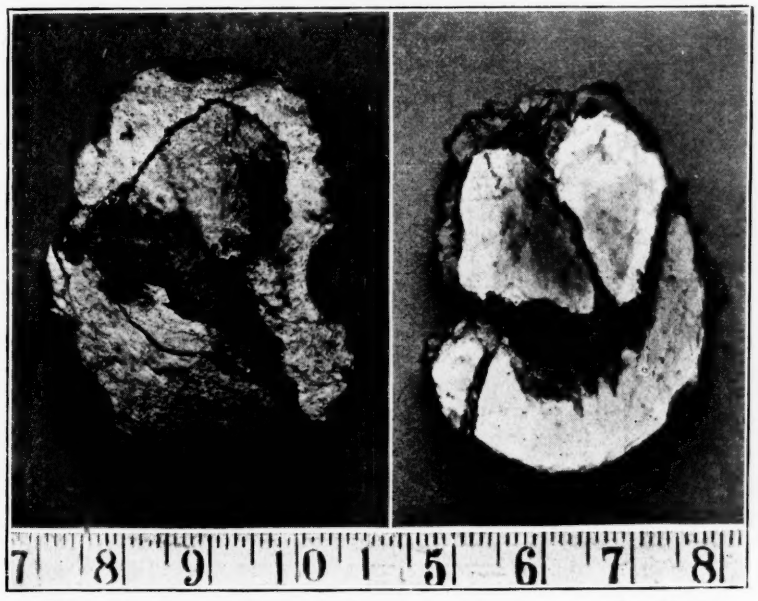


FIG. 611.—*Case* 74. Outer and inner aspects of trepanation block, showing oblique penetration.

Neurological Findings.—Deep reflexes hyperactive; otherwise nothing made out. No hemianopsia.

Operation, 10 a.m. (13 hours).—Novocain. Tripod excision of scalp wound; trepanation *en bloc* (*Fig.* 611); one large fragment of inner table driven edgewise through dura to ventricle; no other fragments recovered. Usual toilette, with dichloramine-T. Incomplete closure, with central drain.

Subsequent Course.—External wound (*Fig.* 612) appeared well; no discharge of cerebrospinal fluid. Patient was about to be evacuated on 11th day, when there occurred a sudden rise in temperature to 103° (*Fig.* 613), with signs of intracranial pressure. A fungus cerebri rapidly developed, with extrusion of remaining fragments of bone and a cerebrospinal-fluid leak. Lumbar puncture: sterile fluid. Cultures from wound: streptococci. Death, 15th day.

Autopsy.—Meningitis and ventriculitis.

FIG. 612.—*Case* 74. On tenth day, before contemplated evacuation.

Only one of the fatalities included in this group died from the effects of the trauma too early for ventricular sepsis to play any rôle.

Case 75.—An unknown civilian (Serial No. 68).

Admission Aug. 20, 1917, 12.30 a.m.—Victim of an air raid; unconscious. No particulars. Gutter wound of posterior parietal region; bleeding cerebral herniation; pressure pneumonia: choked disc and rhythmic respiration.

Operation.—Confined to mere repair of external wound, with control of bleeding from superficial meningeal vessels. No return of consciousness. Death in 24 hours.

Autopsy.—A double track made by fragments of bone, one leading through posterior horn of left ventricle, tentorium, and cerebellum. Blood-clot surrounds hind-brain, and extends up over left cerebral hemisphere.

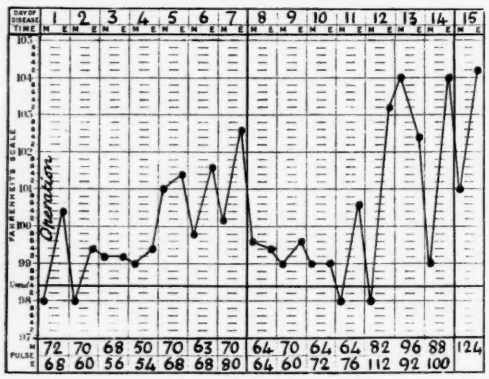


FIG. 613.—Temperature chart of *Case* 74.

Type B.—THE VENTRICLE PENETRATED OR TRAVERSED BY A PROJECTILE.

In this type there were no certified recoveries, and the condition in most instances was a post-mortem finding. Death was due to trauma and hæmorrhage in 8 cases; to secondary infection of the cerebrospinal spaces in 7; to intercurrent causes in 1.

It is not at all improbable that in some of the patients who have recovered, with retention of the foreign body, the missile may actually have penetrated or perforated the ventricle; this can only be surmised, by the help of the three-dimensional study of the course of the projectile, aided by the *x*-ray examination in each case. It is significant, however, that among the fatalities from a lodged projectile, the post-mortem examination showed that the ventricle had been opened in slightly more than half (16 out of 31).

It is interesting to find that the projectile not uncommonly lodges in the ventricle, as though the pool of fluid serves more effectively to check its progress than the cerebral tissue. This was true in 6 of the 16 cases, and in one there were two missiles in the ventricle.

The single case in the series in which the missile, identified as being in the ventricle, was removed at operation, possibly deserves a somewhat detailed report.

Case 76.—Pte. D. Q. (Serial No. 22). **Magnet extraction, after two days, of shell fragment from infected ventricle. Irrigation of ventricle; subsidence of local infection. Death three months later from inanition.**

Admitted Aug. 1, 1917.—Wounded about 11 a.m. of preceding day; a shell fragment penetrated helmet; much bleeding from wound, but no loss of consciousness; left side powerless; not found by bearers till to-day; reached casualty clearing station at 4 p.m.; conscious, but in collapse.

General Condition, Aug. 2, 4 p.m., after 24 hours in resuscitation ward.—Conscious; warm; pulse much improved, 70; headache.

Wound.—Penetrating variety, 2 cm. to right of mid-parietal vertex; no brain extruding. *X*-ray (stereoscopic) report: "Small penetration; projectile in mid-brain; bone fragments in track" (*Fig.* 614).

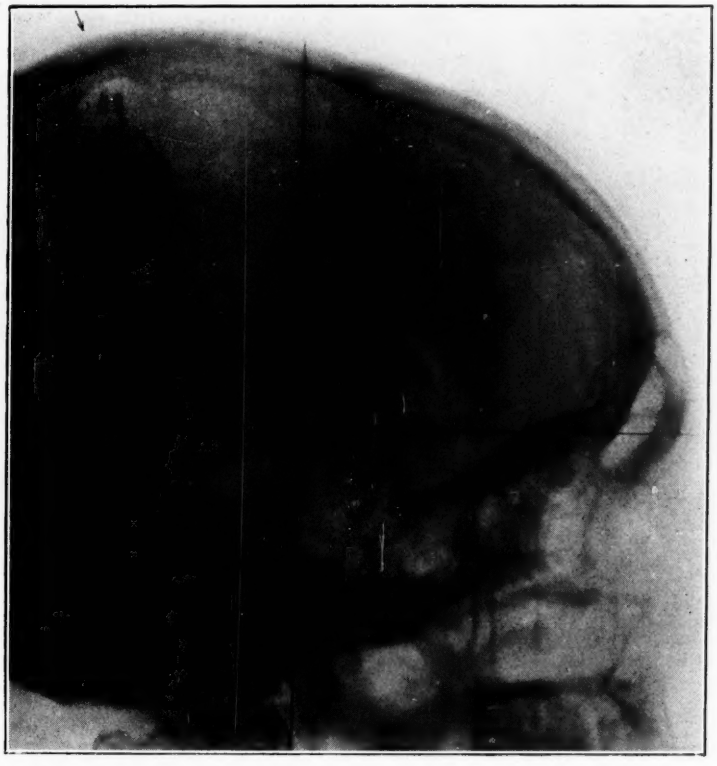


FIG. 614.—*Case* 76. *X*-ray picture showing projectile in ventricle.

Neurological Findings. — Spastic left hemiplegia involving arm, leg, and face, with sensory loss over arm and leg; clonus at knee and ankle; dorsal plantar response. Left homonymous hemianopsia. Optic discs hyperæmic; blurred outlines; cups œdematous.

Operation, Aug. 2, 5 p.m. (53 hours).—Novocain. Curvilinear flap, with excision of wound; enlargement of bony opening; bleeding from longitudinal sinus on picking out superficial fragments, checked by fascial graft; lateral incision of wound in exposed dura; escape of much disorganized brain and clot. Soft catheter introduced, and at depth of 6 cm. enters ventricle; about 20 c.c. of bloody seropurulent fluid removed; culture gave abundant *B. perfringens* and staphylococci. Eusol irrigation into cavity. Several bone fragments removed from track. Insertion of

nail to ventricle, with magnet extraction of 3·8-grm. projectile (*Fig.* 615) on first trial. Small-calibre catheter left in sinus. Closure except for catheter.

Aug. 3.—Temperature 100°. Chief complaint, discomfort in paralyzed side. Some cervical stiffness. Ventricle draining well; culture No. 2: "Cocci and *B. perfringens* in abundance." Aug. 4.—Third culture from ventricle: "Cocci and *B. perfringens*." Aug. 5.—Extensive herpes labialis, with rise in temperature to 102°, but general condition appears much better; rational; talking; taking nourishment well. Aug. 9.—Has had daily gentle irrigation of ventricle through catheter, which has been retained, and has drained well; culture No. 4. Condition excellent; beginning to move fingers on left. Catheter withdrawn. Aug. 10.—Rise in temperature to 102°. (Report of culture No. 4: "Cocci persist, (?) pneumo-cocci. Bacilli rare.") Aug. 13.—Reaction following removal of drain has subsided. Possibly slight fullness in wound. Beginning return of movements in left foot. Sept. 13.—During the month's interval there were ups and downs in the man's condition, with dull and brighter periods alternating. Believing that there must either be an abscess, a ventricular hydrops, or an area of cerebral softening, several exploratory punctures were made in the hemisphere, with negative findings, the ventricle being entered on one occasion (Aug. 28) and found to contain clear sterile fluid. Oct. 4.—Temperature normal for past three weeks, but he remains for the most part dull and unresponsive, with marked inappetence. Slight movements possible in arm and leg, but very little progress being made. Evacuated (71 days).

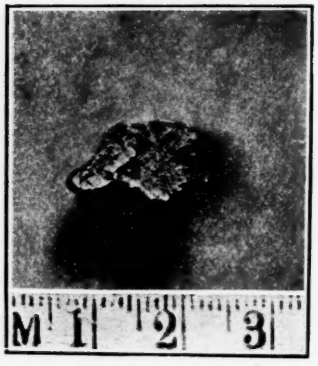


FIG. 615.—*Case* 76. 3·8-grm. fragment, with rubbed edge, removed from ventricle.

Subsequent Notes.—He reached No. 2 Canadian General Hospital in bad condition, bedsores developed, and he died two weeks after his admission.

Autopsy Note.—"Head, only, opened. The semilunar scar over the right parietal area was adherant. There was a considerable amount of scar tissue in the brain substance under this wound. The brain was pale. There was no sign of pus; no abscess, no meningitis."

Death presumably occurred from inanition, as may happen to bed-ridden hemiplegics.

Though the severity of the cerebral injury rather than the early intracranial infection accounts for the death of this man, the experience nevertheless stands as an argument for earlier operation. It is my feeling, so far as head cases are concerned, that the long period so often passed in the resuscitation ward, with the administration of warmth and stimulants, is too serious a loss of time when taken from the standpoint of the possible establishment meanwhile of a serious infection. A cranial operation under combined morphia and a local anæsthetic may be carried out at the same time that warmth, fluids, and stimulants are being administered.

The following, another early case in the series, was also delayed for long in the resuscitation ward. The ventricular perforation played an unimportant rôle, but the case is of interest from other standpoints.

Case 77.—Pte. E. B. (Serial No. 61). **Penetrating shell fragment passing from vault to base through ventricle. Operation, with missile extraction, deferred 22 hours. Gas encephalitis.**

Admission, Aug. 16, 1917, 4 p.m.—No history (helmet worn, cf. *Fig.* 617); critical condition; somnolent. Resuscitation ward 22 hours.

Wound, Aug. 17.—Lacerated, of penetrating type, just to right of mid-vertex;

brain extruding. *X* rays show shell fragment lying beside pituitary fossa, with bone fragments in its path (*Fig.* 616).

Neurological Findings.—No response to stimuli ; apparent paralysis with rigidity of left side, with reflexes increased to clonus, and positive Babinski. Persistent conjugate deviation of head and eyes to right. Profuse sweating.

Operation, 1.30 p.m. (*circa* 32 hours ?).—Excision of scalp wound ; trepanation *en bloc* (*Fig.* 617). Prompt extrusion of clots and disorganized brain. Catheter suction of track, with removal of the 8 fragments of bone shown by *x* rays —some withdrawn in eye of catheter. Bloody cerebrospinal fluid. Catheter enters 13 cm., and detects foreign body. Attempted magnet extraction with an intervening wire nail : first trial unsuccessful : local current switched off. In lieu of magnet a piece of small stomach tube was cut off, inserted to bottom of track, and

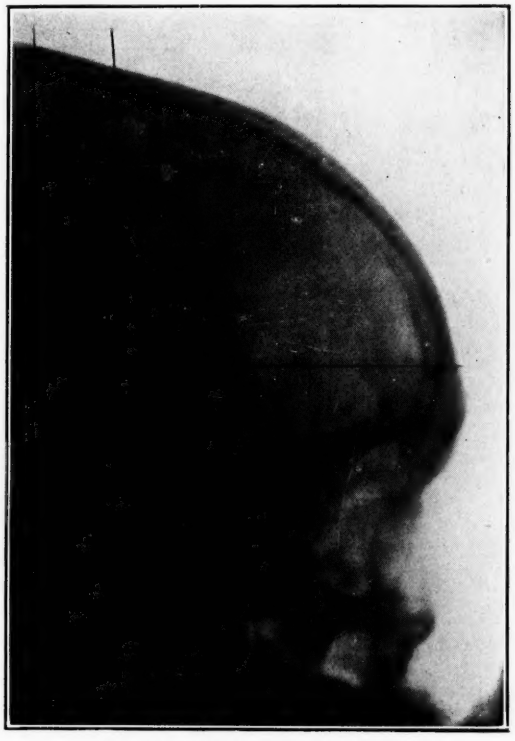


FIG. 616.—Radiogram of *Case* 77.

FIG. 617.—*Case* 77. Bone block and missile with burnished surface.

suction applied ; the missile (*Fig.* 617) was withdrawn in eye of tube (culture, reported following day : *B. perfringens*). Closure of wound by plastic method. Missile weighs 3·5 grm., and shows a burnished surface from helmet penetration.

Aug. 18.—Temperature 99° ; partial return of consciousness. 11 p.m.—Sudden rise of temperature to 104°. Wound re-opened ; stinking gas infection. Eusol irrigation of track continued during night. Aug. 19.—Death at 8 a.m. Temperature 107°.

Autopsy.—Extensive gas encephalitis of entire hemisphere. Track passed parallel to falx through ventricle to temporal lobe beside sella turcica. No apparent meningitis.

Despite the delayed operation, had the wound in this case been left open with direct catheter drainage, as in the preceding one, there would have been a very good chance of recovery. It is in matters of this kind when judgement is put to the greatest test—to close or not to close. It is possible that immediate cover-slip examinations of the deeper wound might serve in place of culture, a report of which means too great delay to be of influence in the question of drainage.

The remaining fatal cases in *Group VI* are as follows: 6 of them were obviously due to the trauma and hæmorrhage alone; 2 to intercurrent causes (exposure and pneumonia); the remaining 7 to sepsis, usually spreading into the ventricle.

The traumatic cases follow.

Case 78.—Capt. L. G. (Serial No. 105). **Multiple wounds; double left temporal cranial penetrations.**

Aug. 22, 1917.—No history. Terminal stage of pressure pneumonia; Cheyne-Stokes respiration. Attempted relief by operation; no anæsthetic; large clot over hemisphere; meningeal and middle cerebral vessels found injured. Temporary improvement. Death 24 hours.

Autopsy.—Track of one missile (*Fig.* 618) to ventricle; the other passes through ventricle, which is filled with blood, and lodges in opposite hemisphere; extensive subdural and intracerebral clot.

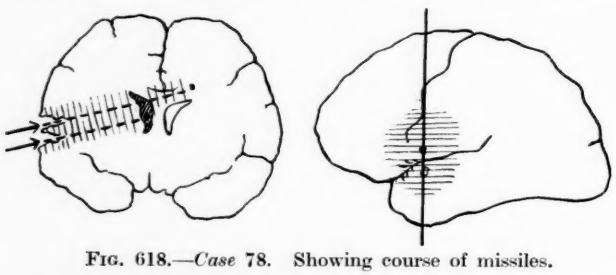


FIG. 618.—*Case* 78. Showing course of missiles.

Case 79.—Pte. J. C. (Serial No. 32). **Multiple penetrations of vertex; serious intracranial lesions produced by small projectile.**

Admitted Aug. 3, 1917.—In resuscitation ward three days unconscious, with extreme spastic rigidity. Transferred to us for operation, Aug. 6, with pulse 150, temperature 102°, respirations rhythmic. Right subtemporal decompression; no anæsthetic. Death in 6 hours.

Autopsy.—Minute perforation to left of median line; sinus uninjured. Clot over entire left hemisphere; thick clot between the two hemispheres. Track passes (*Fig.* 619) through corpus callosum, right lateral ventricle—which is full of blood—to inferior right temporal lobe, where small 0·3-grm. projectile (cf. *Fig.* 619) is lodged.

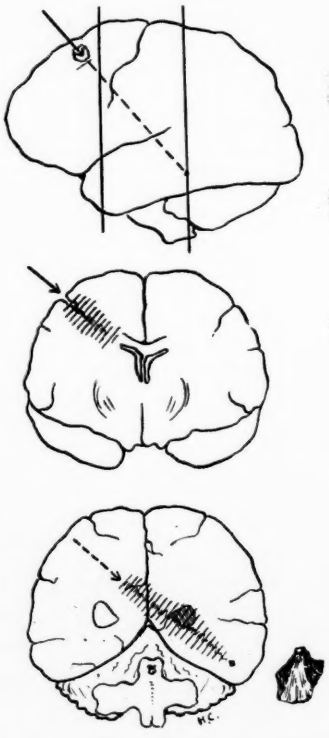


FIG. 619.—*Case* 79. Showing small missile (natural size), and course.

Case 80.—Pte. C. R. (Serial No. 39). **Penetrating wound, right fronto-temporal.**

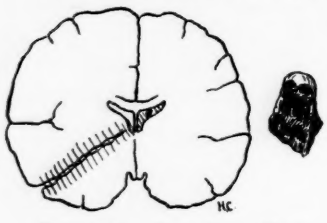


FIG. 620.—*Case* 80. Showing small missile (natural size) lodged in ventricle.

Aug. 6, 1917.—Profoundly unconscious; pressure phenomena. Immediate operation; no anæsthetic; temporal flap; trepanation; large subdural clot evacuated; bleeding Sylvian vein clipped; closure. Death in 19 hours; no return of consciousness.

Autopsy.—Clot over hemisphere incompletely removed at operation. Track of missile: from frontal lobe diagonally into opposite ventricle (*Fig.* 620), where a 1-grm. missile with a burnished face lies free. No gross evidence of sepsis.

Case 81.—Pte. A. H. (Serial No. 63). **Multiple wounds, one penetrating glabella, with projectile lodged in left hemisphere under parietal eminence.**

Aug. 17, 1917.—Profoundly unconscious; pulse 60; papill-œdema; complete right hemiplegia. 11 p.m.—Condition rapidly growing worse; pulse 90 and irregular; choked disc 2 D; right pupil dilated. Attempted left subtemporal decompression; no anæsthetic; film of clot over very tense hemisphere. Temporizing investigation of wound of entrance, which passed through frontal sinus. Death in 4 hours.

Autopsy.—Track of missile from frontal pole of hemisphere into left ventricle, which is distended with blood. A 2·2-grm. projectile (*Fig.* 621) lies in ventricle about opposite posterior end of the thalamus. Entire left hemisphere contused and œdematous.

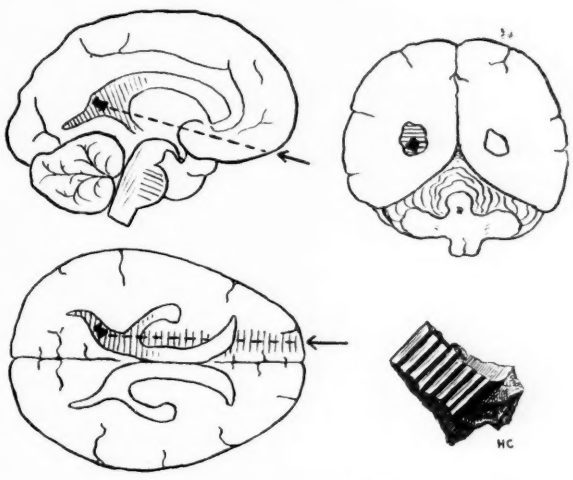


FIG. 621.—*Case* 81. Showing a 2·2-grm. missile, and course to ventricle.

Case 82.—Pte. H. L. E. (Serial No. 88).

Aug. 31, 1917.—Admitted 2 p.m. in critical condition. Large penetrating wound in mid-line at coronal suture; brain extruding. *X*-ray report: "Large foreign body at base near petrous bone" (*Fig.* 622). Resuscitation ward 21 hours. Sept. 1.—Profoundly unconscious; choked disc 1 D; typical longitudinal-sinus syndrome, with spasticities, adductor spasm, clonus, etc.

Operation.—No anæsthetic necessary; trepanation *en bloc*; careful toilette of track, with removal of deep bone fragments; catheter enters 6·5 cm. and detects missile; nail inserted; magnet extraction of 15-grm. missile (*Fig.* 623) on first trial. Consciousness not regained. Death in 24 hours.

FIG. 622.—*Case* 82. *X*-ray photograph showing deep position of large missile, and characteristic track.

FIG. 623.—*Case* 82. Missile (15 grm.) with burnished edge (natural size).

Autopsy.—Meridional fracture lines, extending to base. Track of missile crosses ventricle and enters temporal lobe. Widespread subdural hæmorrhage over left hemisphere.

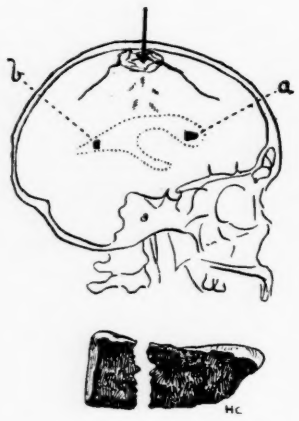


FIG. 624.—*Case* 83. Showing *x*-ray appearance, with position of two pieces of one original rubbed fragment.

Another example, though not included in the operative series, as death took place during the preparation for operation, may be given, as it illustrates the gravitation of missiles which lie free in the ventricle. The sketches made at autopsy tell the story, which therefore needs little context.

Case 83.—Rfm. H. S.

Admitted Aug. 15, 1917.—Comatose. Penetrating wound of mid-vertex, through helmet (rubbed missile); longitudinal-sinus syndrome. *X* rays (stereoscopic) show two widely separated foreign bodies near mid-plane of skull (*Fig.* 624). Death during preparation for operation, five hours after injury.

Autopsy (*Fig.* 625).—The two metal fragments (3 grm.) are evidently from one original piece, and show along one surface the rubbed and deformed margin produced by the helmet penetration (cf. *Fig.* 624).

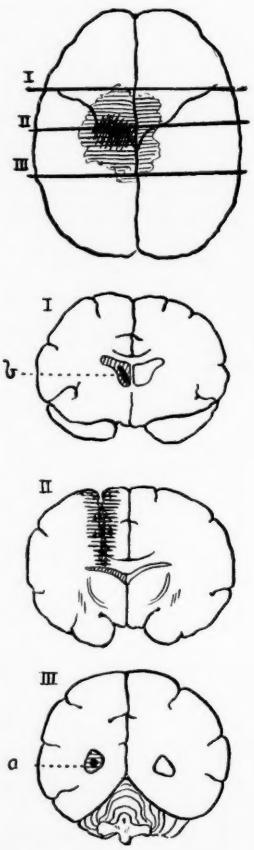


FIG. 625. — *Case* 83. Autopsy findings.

The two examples in this group with a fatality from pneumonia are as follows. In the first, as in the case just recorded, two missiles, a primary and secondary, entered by the same wound.

Case 84.—Pte. S. H. R. (Serial No. 14).

Aug. 1, 1917.—Lying-out case with multiple wounds of leg, arm, and head. Condition bad. Penetrating wound, right temporo-frontal.

FIG. 626.—*Case* 84. Fragments of helmet and shell, both penetrating (natural size).

Operation (24 hrs.).—Novocain. Temporal flap; closure. Pneumonia. Death on 4th day.

Autopsy.—Two tracks lead from the wound of entrance, one from a 1-grm. fragment of helmet (*Fig.* 626) into the right internal capsule, the other from a 0·6-grm. bit of shell through ventricle into opposite parietal lobe (*Fig.* 627). At end of each track is disorganized brain, but no abscess. No meningitis.

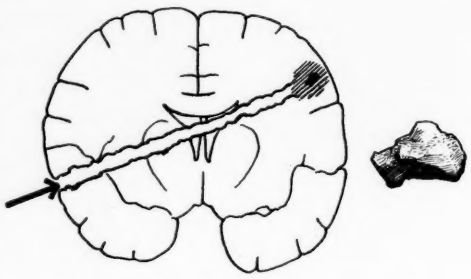
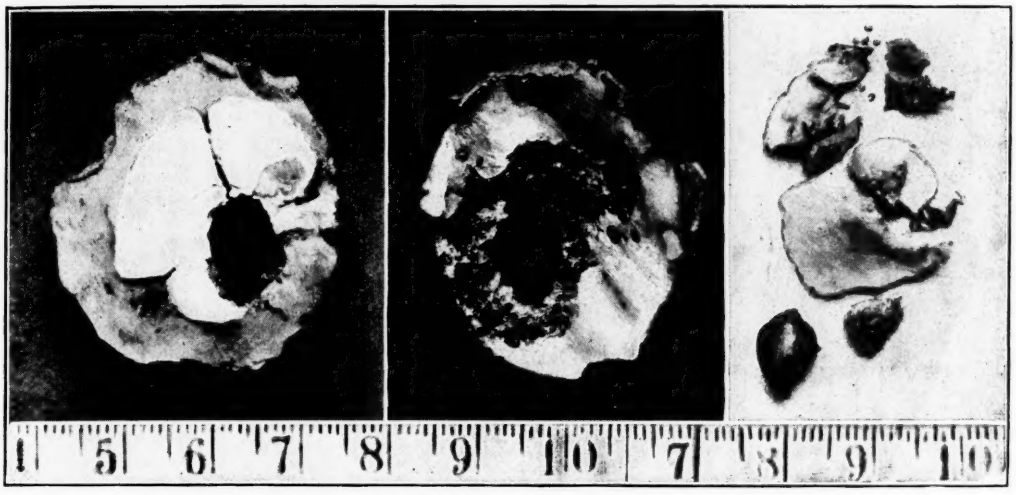


FIG. 627.—*Case* 84. Showing course of shell fragment.

The second of these pneumonia cases is of interest from the fact that, with a mid-line penetration, the bone fragments were showered on one side, while the foreign body entered the other side of the falx.

Case 85.—Pte. C. G. (Serial No. 199). **Mid-line fronto-parietal penetration, traversing ventricle; missile retained; death from pneumonia 10th day.**



FIGS. 628, 629, 630.—*Case* 85. Trepanation block from directly over sinus; bone fragments and small missile with rubbed surface.

Oct. 22, 1917.—Admitted without history: unconscious; breathing badly. Resuscitation ward 6 hours. Mid-line parieto-frontal penetrating wound. *X* rays show missile in right occipital base. Neurological examination unsatisfactory.

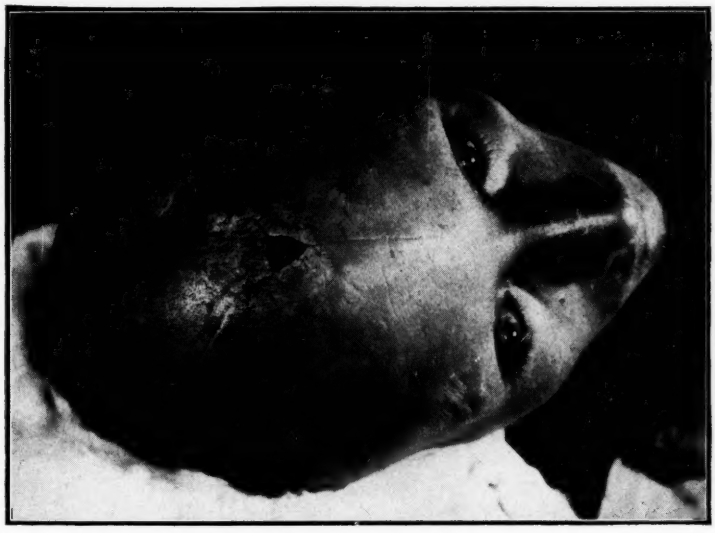


FIG. 631.—*Case* 85. Showing tripod incisions; wound well healed to central point, sixth day.

Operation (6 hrs.) — Tripod incisions, exposing small penetrating wound, with elevated plates of outer table as in a wound of exit (*Fig.* 628). Trepanation *en bloc*, exposing intact sinus bridging a tear in the dura on each side. Through opening on left is a 5-cm. track with bone fragments; on the right a track filled with clot and pulped brain leads to depth through ventricle, which was completely emptied in the process of suction; no attempt made to recover missile. Dichloramine-T. Small catheter left in track; closure to central point (cf. *Fig.* 631).

Oct. 23.—Consciousness regained. Lumbar puncture: 20 c.c. bloody fluid (culture sterile). Purulent bronchitis, with excessive secretion. Catheter withdrawn on 4th day; wound intact; primary healing (*Fig.* 631). Neurological condition excellent, but continuance of pulmonary symptoms with fever. Death on 10th day.

Autopsy.—Bronchopneumonia. Track in right hemisphere leads through ventricle to base of occipital lobe, where is a foreign body in a small encapsulated abscess. No meningitis; no ventriculitis.

In the remaining seven cases death was in all certainty due to a meningeal or ventricular infection. The opinion has been expressed that small foreign bodies are well tolerated and should be left to work out their own salvation, and the investigation of late cases by Tuffier and by Holmes has been interpreted as an indication that these cases do well. It is true that, barring an occasional secondary abscess, they do well if they pass by the stage of early septic complication. Unfortunately, studies based on late results do not take into account the large percentage of cases which have succumbed early; and in fact these early septic complications are so frequent, that one may with all conservatism follow the rule 'always remove a foreign body when possible, unless the act of removal is likely to increase the damage already made by the penetration.'

FIG. 632.—Metal fragments from *Case* 86.

In many instances infection had become established from long lying out, as the first of the following cases indicates.

Case 86.—Sgt. E. R. (Serial No. 29).

Aug. 3, 1917.—Lying out 72 hours. Penetrating wound of frontal by three fragments (*Fig.* 632) of driving band of shell. Probably without helmet.

Operation.—Pulped lobe, with clot in ventricle. Two metal fragments extracted by magnet. Closure. Death in 24 hours.

Autopsy.—Early meningitis and ventriculitis. Fragments of bone in ventricle, and third piece of metal beyond it.

Case 87.—Sgt. R. K. (Serial No. 85).

Aug. 31, 1917.—Multiple wounds. Penetrating wound under helmet: left orbito-temporal. Irrational. Missile in opposite hemisphere. Flap operation; toilette of track; bloody cerebrospinal fluid (culture: staphylococci); gutta-percha drain. Urotropin. Sept. 2.—Lumbar puncture: 20 c.c. bloody fluid (culture sterile). Purulent bronchitis. Sept. 3.—Perfect

FIG. 633.—*Case* 87. Showing position of entrance wound with drain and flap incision, fourth day.

healing of external wound (*Fig.* 633). Continued cough. Better for following two days, then sudden rise in temperature, and death on 8th day, with evident pneumonia and meningitis.

Autopsy.—Track runs downward across brain, through falx and ventricles, to small 0·9-grm. fragment in centre of abscess (*Fig.* 634). Track infected; ventriculitis; meningitis; consolidation of entire right lung.

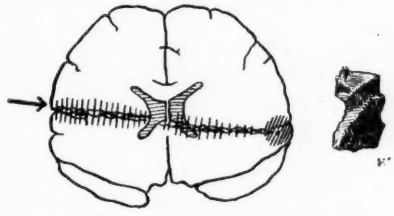


FIG. 634.—*Case* 87. Showing track and missile (natural size).

Case 88.—Sec.-Lieut. J. H. (Serial No. 119).

Sept. 20, 1917.—Minute penetrating wound in auriculo-temporal region, with chain of five small metal fragments. Aphasia; contralateral paralyses. Careful operation, with usual treatment of track; missiles not secured. No improvement in condition; fever. Sept. 22.—Lumbar puncture: bloody fluid under tension (cultures sterile). Death on 4th day.

Autopsy.—Marked comminution of petrous bone, with meningeal infection. Temporal lobe much disorganized, with track containing bone fragments; deepest missile leads into left ventricle, which is full of seropurulent fluid.

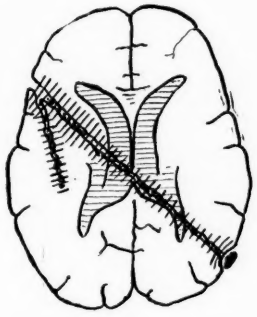


FIG. 635.—*Case* 89. Showing track and positions of two fragments.

Case 89.—Rfm. H. H. A. (Serial No. 123).

Sept. 20, 1917.—No history obtainable; probably lying-out case. Irrational; restless; irritable; critical condition. Penetrating wound of left temporal; brain extruding. Two missiles shown by *x* rays, one in left temporal, the other in right occipital lobe. Operation, requiring general anæsthetic. Usual track treatment by suction. Dichloramine-T. Missiles not secured. Death in 24 hours.

Autopsy.—Septic track through ventricle and brain to outer surface of opposite occipital lobe; missile subdural (fragment lost). Extensive encephalitis of left brain, with secondary missile (*Fig.* 635).

Case 90.—Pte. W. D. N. (Serial No. 131).

Sept. 22, 1917.—Deep stupor. Pulse 98. Two wounds, right parieto-temporal; one penetrating; brain extruding. No *x*-ray examination.

Operation.—Evacuation of clots, disorganized lobe, and bloody fluid. Continued bleeding from depth checked with difficulty. Incomplete closure. No return of consciousness. Death on 5th day.

Autopsy.—Widespread infection. Track leads across brain through ventricles, which are distended with blood-clot. Small 0·8-grm. bit of shell lies in abscess cavity under opposite meninges. Blood-clot in all cerebrospinal spaces (*Fig.* 636).

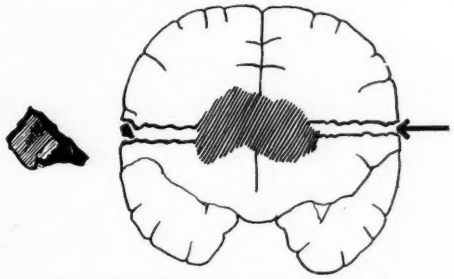


FIG. 636.—*Case* 90. Showing track through ventricle, and missile (natural size).

Case 91.—Cpl. R. J. H. (Serial No. 212).

Oct. 27, 1917.—Wounded 24 hours ago. Dull and disoriented. Small penetrating wound of left occiput. Brain extruding. *X* rays show small missile in parieto-frontal region, mid-line (*Fig.* 637). Right homonymous hemianopsia. Papillœdema.

Operation.—Usual procedure: trepanation *en bloc*; evacuation of clots, pulped brain, and cerebrospinal fluid; suction treatment of track to depth of 15 cm.; no bone fragments secured; direct drainage.

Oct. 29.—Headache. Lumbar puncture: yellow fluid, sterile on culture. Oct. 31.—Lumbar fluid shows streptococci. Death without usual high temperature.

Autopsy.—Track of small 0·5-grm. shell fragment (*Fig.* 637) passes from tip of occipital lobe through left ventricle and falx to right frontal lobe. Ventricle infected; basilar meningitis.

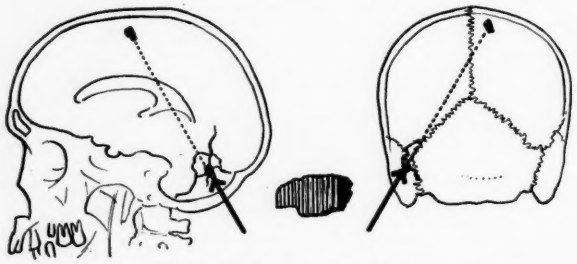


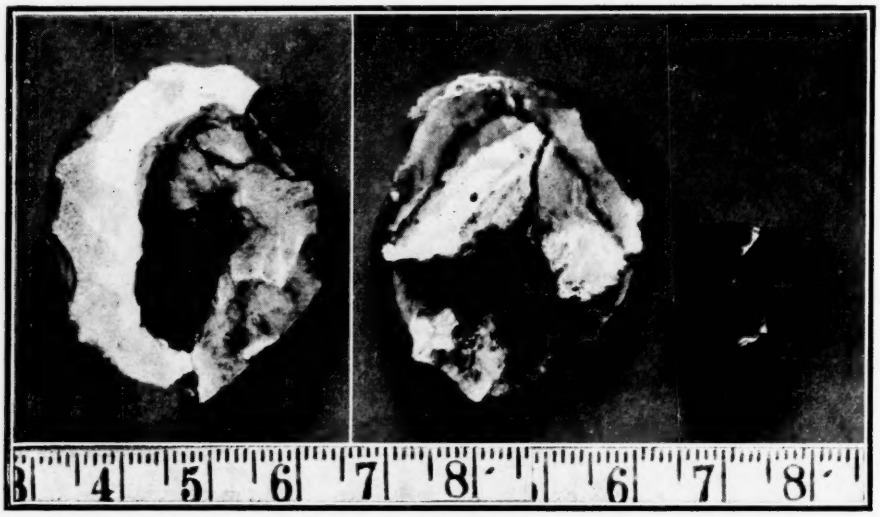
FIG. 637.—*Case* 91. From *x*-ray picture, showing position of missile (natural size).

The last of these cases may be given in a little more detail, for it shows how long a patient may hold out with a penetrated and infected ventricle.

Case 92.—Pte. E. H. (Serial No. 117). **Double cranial injury, from a split projectile: one fragment from fronto-parietal penetration free in the ventricle; the other lodged in parieto-occipital vault, with depressed fracture.**

Admission, Oct. 9, 1917, 4 p.m.—Wounded at 11.30 a.m. Wearing helmet. Temporarily unconscious; recovered and walked in; headache; vomited once. General condition good; conscious; pulse 70; normal mentality.

Wounds.—(1) Lacerated, gutter type, right parieto-occipital; (2) Lacerated, penetrating type, right parieto-frontal; (3) Left scapular injury. *X* rays show



FIGS. 638, 639—*Case* 92. Block from posterior lesion, with lodged and burnished missile (*Group III* type).

posterior depressed fracture with superficial missile; anterior fracture with indriven bone and missile.

Neurological Findings.—Practically nil. Deep reflexes over active, but equal.

Operation, 10 p.m. (11 hours).—Novocain.

Anterior wound: Tripod incision (cf. *Fig.* 640); trepanation *en bloc*: all fragments of inner table missing. Bleeding arachnoid artery caught with silver clips. Track leading across hemisphere to falx. Pulped brain and several bone fragments removed in process of usual toilette. Escape of bloody cerebrospinal fluid, with complete lowering of tension. Attempt at magnet extraction of missile unsuccessful. Dichloramine-T. Closure of dura and scalp.

Posterior wound: Tripod incision. Depressed fracture from an oblique blow, with lodged 8·3-grm. shell fragment (*Figs.* 638, 639) evidencing helmet penetration. Trepanation *en bloc*. Dura found punctured. Evacuation of disorganized brain. Closure; no drain.

Oct. 12.—Troublesome bronchitis. Temperature remains elevated. Extensive herpes labialis. Stiffness of neck. Lumbar puncture, with 20 c.c. yellow fluid (sterile on culture). The scalp incisions in good condition (*Fig.* 640). Oct. 14.—Mentality remains unimpaired; no neurological symptoms, but evidently some intracranial infection. Puncture repeated: 30 c.c. straw-coloured fluid (culture sterile). Oct. 16.—Continued high temperature (*Fig.* 641). No discomfort but from stiffness of neck.

FIG. 640.—*Case* 92. Scalp wounds on third day.

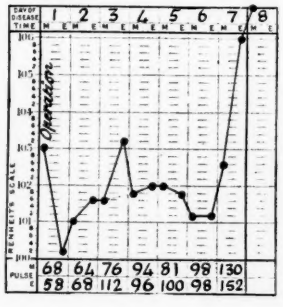


FIG. 641.—Temperature chart of *Case* 92.

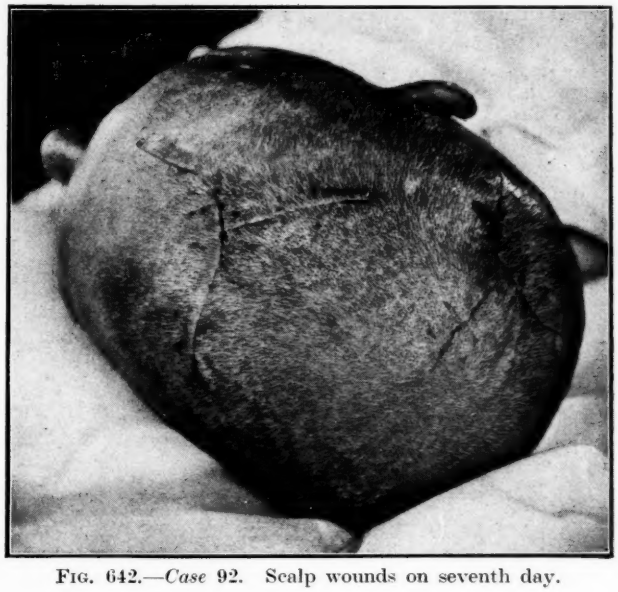


FIG. 642.—*Case* 92. Scalp wounds on seventh day.

Condition of external wounds perfect (*Fig.* 642). Oct. 17.—Death, with temperature of 106·5°.

Autopsy.—No evidence of meningeal infection.

Contusion of hemisphere under the posterior wound, without infection; also of fronto-parietal track, which leads across hemisphere and penetrates falx. The left ventricle is distended with pyoserous bloody fluid, with 3-grm. shell fragment lying free in posterior horn; it shows evidence of having perforated the helmet. The right ventricle is without evidence of infection. The foramen of Monro appears to be sealed (*Fig.* 643). The two missiles fit together, and are evidently from the

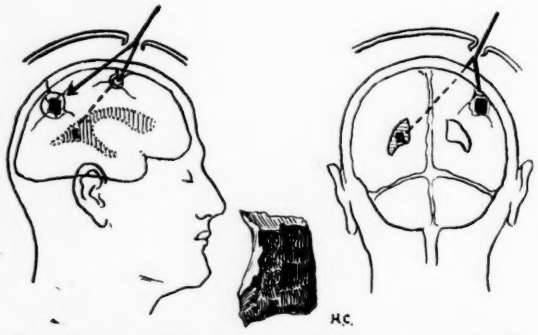


FIG. 643.—*Case* 92. Diagrams to show course of split projectile from site of helmet penetration.

same original piece, and were probably separated, as in *Case* 63, during passage through helmet.

This case, like others in the series, shows how little evidence of what may be taking place in the track within the brain is given by the appearance and condition of the external wound.

Group VII.—CRANIO-CEREBRO-FACIAL INJURIES.

The sixteen cases comprising this small group are put in a separate category with some misgivings. Subsequent studies of a larger series may make it seem unnecessary to separate them from the preceding or following groups in which they might be made to fall, or may suggest for them some still better disposition. They represent injuries, usually of a severe nature, in which, in addition to a wound exposing the brain, either the ethmoid cells and nasal sinuses have been opened, often with an associated injury of the orbit—a *cranio-cerebro-nasal type*; or the ear and petrous bone have been involved—a *cranio-cerebro-aural* type. In both types there is an added risk of secondary meningeal infection over and above that entailed by the original implantation of infective material directly in the wound.

Admittedly it is not always possible to sharply demarcate these cases. Some of them might well be included with the perforating wounds in the following section, and, on the other hand, examples of serious injuries to the petrous bone with dural penetration and fatal meningitis have been included in earlier sections (e.g., *Case* 88 in *Group VI*). However, in the long run, the cases are of a more immediately serious nature, and are associated with wounds which pass from face to cranium or the reverse. Some, particularly those involving the orbito-frontal region, are of a more or less bursting character, with marked elevation of large bone fragments, as will be seen.

Included in this group are 8 orbito-frontal cases, with 3 recoveries; and 7 auro-temporal cases, with 1 recovery. The mortality, therefore, was 73·3 per cent among this small number. In several of them, recorded as operated cases and therefore included in the series, the procedure consisted of little more than the mere cleaning up of the external wound and the instituting of some form of irrigation treatment.

A.—ORBITO-FRONTAL TYPE OF CRANIO-CEREBRAL INJURIES.

The three recoveries were as follows. The first of the cases is one of comparatively mild type.

Case 93.—Rfm. E. L. (Serial No. 127). **Fronto-nasal penetration, with injury of longitudinal sinus and indriven bone fragments. Operation. Recovery.**

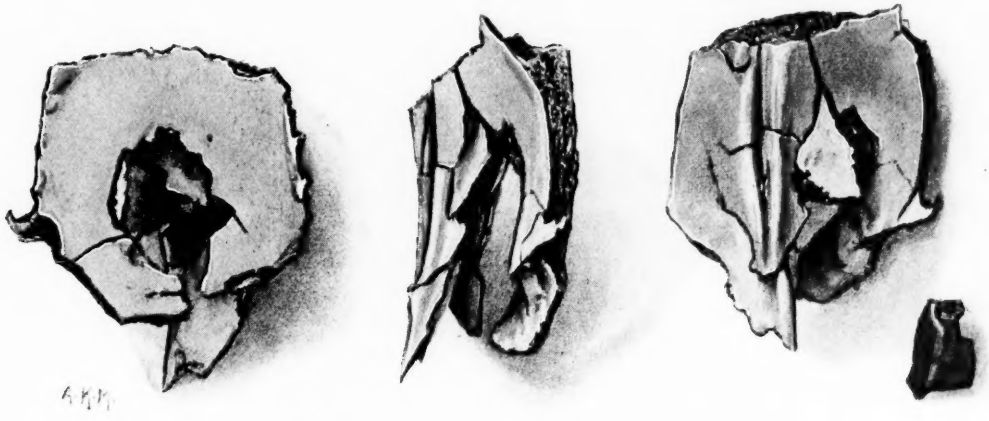
Admitted Sept 21, 1917, 5.40 p.m.—No history obtainable, owing to mental state. Resuscitation ward over night.

Condition, Sept. 22, 9 a.m.—Restless ; unbalanced mentality ; pulse 66 ; body warm. (Almost stone deaf from childhood.)

Wound.—Lacerated mid-line gutter wound of scalp 5 cm. long, extending downward to glabella ; slightly to left. *X* rays show fracture of frontal, with bone fragments indriven ; small projectile imbedded in ethmoid on level of nasion.

Neurological Findings.—Tossing ; mumbling ; responses unintelligible. Reflexes hyperactive throughout. Examination otherwise negative.

Operation, 9 a.m.—Novocain. Excision of scalp wound, exposing perforation in bone just above frontal eminences. Trepanation *en bloc*, with removal of upper part of sinuses (*Figs.* 644–646). Extruded brain, filling sinuses. Dura found lacerated to right of mid-line ; bleeding from longitudinal sinus easily checked by silver clip. On cleaning brain and clots from base of frontal sinuses, a fracture was



FIGS. 644, 645, 646.—*Case* 93. Trepanation block, entering frontal sinuses : from three aspects, with missile.

disclosed entering ethmoid cells, with lodgement of a small 1·6-grm. projectile (*Fig.* 646) : surface burnished from helmet. Right frontal lobe underlying dural laceration considerably pulped. Suction procedure, with recovery of fragments of bone at 3 cm. depth. Dichloramine-T in sinuses. Partial closure, with rubber catheter drain.

Post-operative Course.—Infection of scalp wound, which was opened at upper end and drained. A considerable rise in temperature on the 4th day, and again on the 17th day to 104°. Otherwise no untoward symptoms. Abundant discharge from sinuses ; continued use of dichloramine-T, with drain until Sept. 21, when drains were removed and there was no further discharge. No apparent mental symptoms. Evacuated Sept. 23 (31 days).

Subsequent Report.—Dec. 12, 1917 (letter from father).—At King George Hospital since Nov. 7. Wound healed ; up and about ; feels well.*

The next case is remarkable for the large projectile, and for the recovery after a badly infected and complicated wound.

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* Since these notes, the boy's father reports that he had been very well, but after attending a concert he had a series of fits, and died on Jan. 4 in status epilepticus. An autopsy was held, and showed no abnormalities aside from the healed wound and a tuberculous spleen. This was the first convulsion he had had.

Case 94.—Pte. P. T. (Serial No. 129). **Fronto-orbital penetration by a 47-grm. projectile. Gas infection. Operation. Recovery.**

Admitted Sept. 21, 1917, 6.45 p.m.—Transferred for operation Sept. 22, at 2.30 p.m., *circa* 30 hours after injury.

General Condition.—Semi-conscious, but can be roused. History vague: thinks he was wounded going over parapet two days ago. Helmet perforated (burnished projectile). Body warm; pulse 80; temperature 100°. No irritability or restlessness.

Wound.—Circular; left frontal eminence; occluded by extruding brain with a gassy odour. Protrusion and ecchymosis of left eye. *X* rays show large foreign body partly imbedded in orbit (*Figs.* 647, 648).

FIG. 647.—*Case* 94. Lateral *x*-ray photograph.

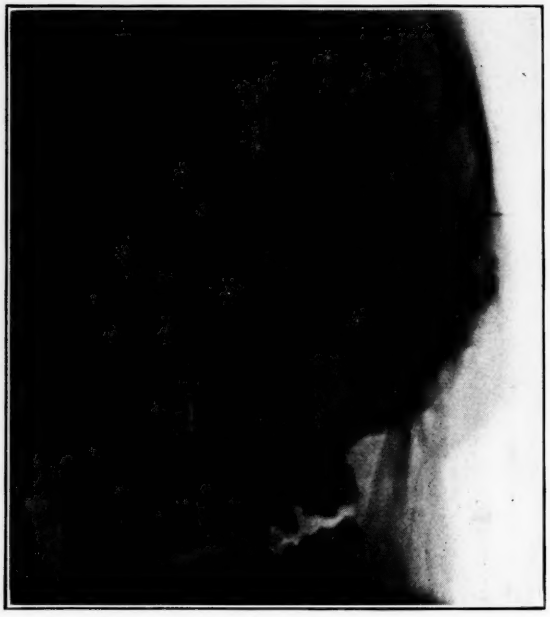
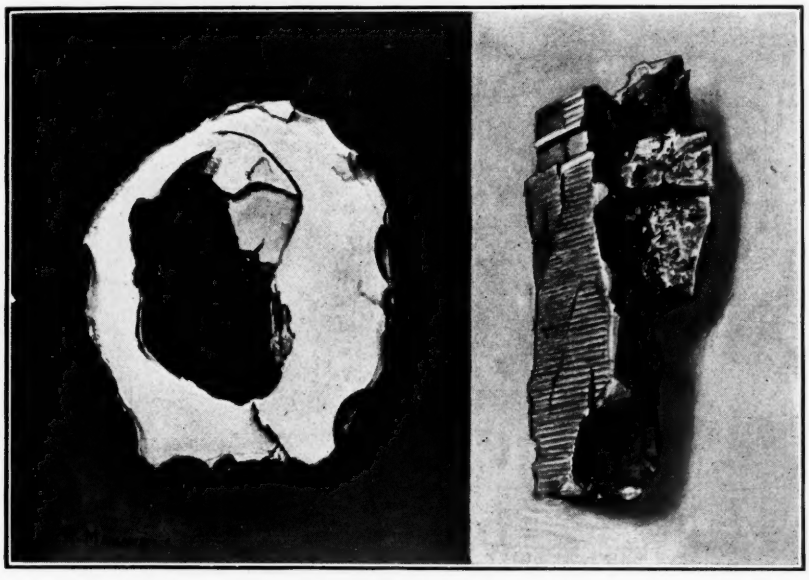


FIG. 648.—*Case* 94. Frontal *x*-ray photograph.

Neurological Findings.—No mental disturbance apparent. Marked exophthalmos of left eye, with blindness and immobility of globe; pupil dilated; ptosis of lid. Increased deep reflexes. Patient right-handed.

Operation, 2.30 p.m. (30 hours).—Novocain. Tripod incision; trepanation *en bloc* (*Fig.* 649). Complete absence of fragments of inner table; radiating lines of fracture pass down across the frontal bone. Large opening in dura occluded by stinking fungus, which was blunt-spooned away. Track leads at 3-cm. depth to upper end of missile, which was wedged too securely for withdrawal. Fragment loosened by magnet and withdrawn; extremely foul odour; weight 47 grm.; corners of the lower end burnished by passage through helmet (*Fig.* 650). Track cleansed by suction method, including the entire pulped tip of lobe; several bone fragments removed. Opening the size of a sixpence through broken roof of orbit; orbital fat crushed and infected. Large cavity filled with cotton pledgets dampened with dichloramine-T. Partial closure of incisions; direct drainage. Cultures: *B. perfringens* and staphylococci; no streptococci.

Post-operative Course.—For two or three days the wound looked very badly, and for a week retained its foul gassy odour. The fresh incision became infected, and had to be opened and drained (*B. perfringens*). The temperature remained low



FIGS. 649, 650.—*Case* 94. Trephine block and missile (natural size), showing rubbed edges from helmet penetration.

from the outset (*Fig.* 651). The fungus became covered with a slough, and great difficulty was experienced in securing proper drainage from the infected orbit, as the fungus tended to occlude the wound. Every second day for ten days a lumbar puncture was necessary in order to collapse the fungus sufficiently to expose the

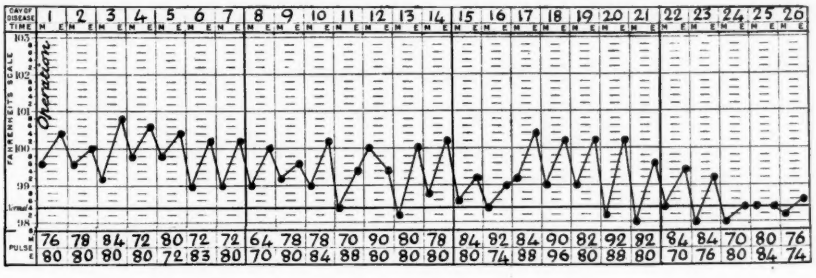


FIG. 651.—Temperature chart of *Case* 94.

opening into the orbit (*Fig.* 652) and permit the placement of proper drainage. The fluid was always clear and sterile. Dichloramine-T was used throughout; the sloughs finally separated, and by the 20th day the fungus began to subside. Finally the wound was grafted. Patient was evacuated in excellent condition on the 45th day, after being up for ten days.

Subsequent Report.—Nov. 14, No. 16 General Hospital.—"No positive clinical evidence of damage to frontal lobe . . . left blindness with optic atrophy; ptosis; paralysis of the superior rectus muscle . . . no other neurological abnormalities Evacuated to England." No subsequent report.

This example of gas infection speaks well for the open treatment of such conditions with dichloramine-T. It is possible that some of the difficulties of after-treatment might have been overcome had an immediate enucleation of the eye been performed, with direct drainage through the roof of the orbit.

FIG. 652.—*Case* 94. Showing collapse of fungus after lumbar puncture, giving access to orbit.

In the following case the orbito-frontal injury was received in the other direction—through orbit to frontal lobe.

***Case* 95.—Pte. S. B. (Serial No. 139). Orbito-fronto-cerebral penetration by 53·2-grm. shell fragment. Recovery.**

Admission **Sept. 26, 1917, 4.30 p.m.—Injured 9 hours before. Missile passed under helmet; knocked down; no loss of consciousness.**

***General Condition.*—Good. Patient conscious and rational. Pulse 80.**

***Wound.*—Irregular lacerated; in region of left eyebrow; lids swollen and closed. Narrow**

FIG. 653.—*Case* 95. Frontal radiogram.

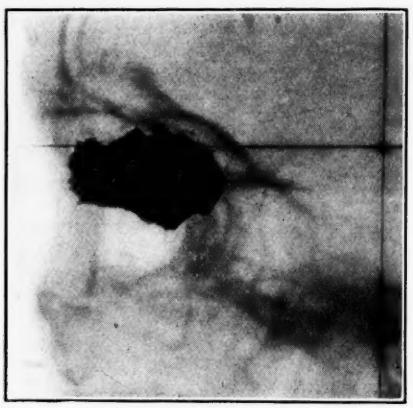


FIG. 654.—*Case* 95. Lateral radiogram.

bridge of upper lid remains intact (cf. *Fig.* 656). *X*-ray report: "Large metal fragment in orbit" (*Figs.* 653, 654).

***Neurological Findings.*—Negative.**

***Operation*, 7 p.m. (12 hours).—Novocain. Slight enlargement of wound, without**

excision. Extraction of large 53·2-grm. missile (*Fig.* 655), which had passed through supraorbital ridge and become securely wedged deep in orbit (chloroform necessitated for its extraction). Roof of orbit had been torn away, widely exposing base of frontal lobe, from site of supra-orbital notch through frontal sinuses and inwards to the anterior ethmoid region. Enucleation of collapsed eye-ball. Dichloramine-T ; full drainage.

Post-operative Course.—Daily dressings of wound (*Fig.* 656). Recovery uncomplicated, except for an oculo-motor paralysis of the right eye which appeared about the 10th day. Highest temperature 100°. Protruding brain well healed over. Evacuated Oct. 23.

Subsequent Reports.—No. 12 General Hospital.—Had received, Sept. 26, 1000 units antitetanic serum. No second injection. Developed tetanus, Oct. 30. Recovered. Evacuated to England, wound healed, good condition, Nov. 8. Feb. 21, 1918 (by letter from Medical Officer, Bath War Hospital).—After discharge of bone fragments, left eye has practically healed ; normal movements regained in right eye ; good condition.

FIG. 655.—Projectile from *Case* 95 (natural size).

FIG. 656.—*Case* 95 on tenth day.

The Fatal Cases.—The other five cases which fall in this cranio-cerebro-nasal category all succumbed ; most of them were hopeless from the outset. The histories follow. In the first, a large unsuspected abscess formed in the relatively undamaged hemisphere.

Case 96.—Sgt. C. C. (Serial No. 50). **Multiple wounds. Large shell fragment penetrating frontal region, with elevation of area of sinuses. Cerebral abscess. Death 4th day.**

Admission, Aug. 14, 1917, 6.15 p.m.—Insists that he was wounded two days before, and that he made his way back alone to aid station. Has had vomiting and headache.

General Condition.—No apparent shock ; pulse 80 ; replies with intelligence to questions.

Wounds.—(1) Large circular ragged penetrating wound of entrance at angular process, right frontal ; brain and clots extruding ; some fresh bleeding ; ecchymosis of eyes ; palpable loose fragments of frontal area ; (2) Gutter wound of scalp above left ear ; (3) Penetrating wound of chest through right shoulder ; (4) Penetrating wound of arm ; (5) Penetrating wound of right cheek. *X*-ray picture (*Fig.* 657) of head shows large projectile in mid-frontal region ; extensive fracture, with elevation of frontal area.

Neurological Findings.—Easily roused, and responds readily, though somewhat hazily. No disorientation or other mental loss observable.

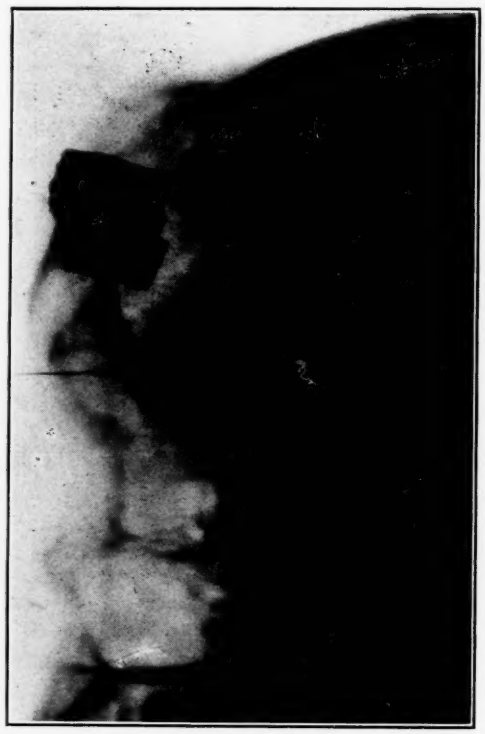


FIG. 657.—*Case* 96. Radiogram (one-half natural size).

Operation, 11 p.m. (? 48 hours).—Novocain. Repair of extensive fracture; entire upper portion of frontal sinuses found elevated and completely detached; area removed, with large 50-grm. missile (*Fig.* 658). Radiating lines of fracture run backward, with many loose plates of bone: left in place. Ragged tear in dura over right frontal lobe; much disorganized brain cleaned away. Wound left open. Carrel-Dakin treatment.

Aug. 17.—Very good condition for first three days. Daily dressings. Cultures from wound surface showed *B. perfringens* in abundance, but there was no tendency to fungate. Temperature 99° to-day; pulse 110. Aug. 18.—Some headache. Lumbar puncture: fluid clear, and straw-coloured (culture negative). No clinical evidence of meningitis. Later in the day became unconscious; temperature rose to 105°. Condition unexplained. Death.

Autopsy.—On removing brain, no evidence of meningitis. Surface of the damaged right frontal lobe covered by superficial slough, at back of which the hemisphere appears normal. The left frontal lobe, however, is occupied by a huge, partly encapsulated abscess, extending back almost to the Rolandic area, and leaving only a thin shell of brain. This abscess communicated with wound through a small punctured opening in the dura at the anterior tip of the lobe; puncture not observed at the operation.

FIG. 658.—*Case* 96. Showing detached block of supra-orbital region, with 50-grm. projectile (natural size).

The following is an example of an unpromising condition for which, after a period of procrastination, one may at times be encouraged to intervene, despite the seemingly hopeless outlook.

Case 97.—L.-Cpl. T. K. (Serial No. 79). **Severe orbito-frontal perforating wound from rifle ball. Gas encephalitis. Death.**

Admission, Aug. 27, 1917, 7.10 p.m.—History unreliable : says he was wounded three days ago and has been lying out. Case regarded as unoperable : sent to resuscitation ward.

General Condition, Aug. 28, 3 p.m.—Good ; conscious ; warm ; pulse 80.

Wounds.—Small entrance wound over left malar eminence. Eye completely pulped. Large stellate wound of exit over right supra-orbital area (*Fig.* 659), with extruding brain and bone. *X* rays show fracture through sinuses, with elevation of fragments ; two small projectiles in antrum.

Neurological Findings.—Memory very defective. Orientation much impaired. Listless and vague in answers ; irritable. No paralyses.

FIG. 659.—*Case* 97. Showing wound before operation.

Operation, 3 p.m. (*circa* 48 hours).—Novocain. Repair of ragged frontal wound, with removal of large pieces of dislodged sinuses and a small bit of jacket of rifle ball. Very large opening in dura 3 cm. in diameter, from which bleeding and lacerated brain extrudes. Track leads through ethmoid region into orbit. Eye-ball, which had been traversed, enucleated. No attempt at closure. Carrel-Dakin treatment.

Aug. 30.—Complete loss of inhibitory faculties ; singing ; restless ; reaching for imaginary objects ; impossible to keep him in bed or to keep an intact dressing. Death Aug. 31, with temperature of 103°.

Autopsy.—Both frontal lobes pulped and disintegrated, and entire anterior half of right hemisphere softened and hæmorrhagic. Odour of gas infection. Linear fractures pass from large anterior defect back as far as parietal eminences.

The following was a similar and equally desperate case, with, however, a temporary promise of recovery.

Case 98.—Sig. G. F. (Serial No. 114). **Orbito-frontal perforating wound with large cerebral hernia. Death 6th day.**

Admission, Sept. 20, 1917, 11.30 a.m. — No reliable history was obtainable. Irrational ; disoriented for time and place ; quiet. Condition good. Pulse 64.

Wounds.—Multiple. Small wound of entrance in left temporal region (*Fig.* 660), with exit through orbito-frontal area, destroying eye ; large cerebral herniation.

Additional wounds of right scalp and right shoulder. *X* rays show extensive fissures of frontal and parietal bones.

Neurological Findings.—Aside from disordered mentality, no positive findings.

Operation, 2 p.m. (*circa* 6 hours ?).—Chloroform. Enucleation of collapsed eyeball; removal of free fragments of bone from orbit; frontal and ethmoid sinuses widely opened. Wound Carrelized, tubes being led in through wound of entrance.

FIG. 660.—*Case* 98. Showing wound entrance and exit, before operation.

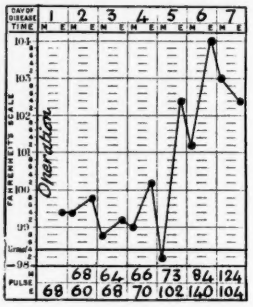


FIG. 661.—Temperature chart of *Case* 98.

Post-operative Course.—Condition remained very promising for three days, despite the continued extrusion of large amounts of cerebral substance into the orbital cavity. A marked rise in temperature occurred on Sept. 24 (*Fig.* 661), and death the following day.

Autopsy.—Extensive basilar meningitis, apparently due to fissured cribriform plate causing tear in overlying dura. No evident cerebral œdema or encephalitis.

The next case exemplifies further the chief hazards of these low frontal injuries—namely, a fracture of the ethmoid, with a meningo-nasal communication.

Case 99.—Pte. D. H. (Serial No. 90). **Fronto-orbital gutter wound; laceration of dura; fracture of ethmoid. Cerebrospinal rhinorrhœa. Pneumococcus meningitis.**

Admission, marked 'urgent,' Sept. 3, 1917.—Bleeding from wound; anæmia; irregular feeble pulse; profoundly unconscious; cold and wet. Immediate operation.

Wound.—Gutter type (*Fig.* 662), vertical, through fronto-orbito-temporal region; no brain extruding.

Operation.—Excision of scalp wound, with ligation of bleeding vessels. Gutter wound of frontal angle, with large indriven piece of bone widely lacerating dura; radiating lines of fracture. Malar bone entirely dislodged, with fractures of zygoma and external orbital plate. Partial closure; drainage.

Sept. 4.—Cerebrospinal rhinorrhœa; evident meningitis, probably pneumococcal. Lumbar puncture, with only 3 c.c. fluid obtained (culture: pneumococcus). Death in 48 hours.

Autopsy.—Several lines of fracture radiate from defect, and cross cribriform plate to opposite side. Extensive basilar meningitis, spreading chiefly over right hemisphere.

The remaining case in this group properly belongs among the perforating cases, where one very much like it (*Case* 109) will be found. The wound traversed the orbito-nasal region, much as in the attempted-suicide type of wound, with division of the optic nerves. The case is placed here, however, as the ultimate fatality was due to an ascending infection from the nasal cavity. Nothing more than slight enlargement of the wound of entrance, with drainage, was possible; and such a case might with some justice be omitted in quoting statistics of an operative series, were it proper to eliminate any case whatsoever.

FIG. 662.—*Case* 99. Showing wound before operation.

Case 100.—Rfm. J. T. (Serial No. 132). **Perforating temporo-orbital wound. Fracture of ethmoid. Temporizing operation. Death 10th day.**

Sept. 20, 1917.—An 8-grm. shell fragment (*Fig.* 663) passed from the right temporal region, just grazing the pinna, to the left orbit, where it lodged in the upper lid. The patient, profoundly unconscious, was regarded as moribund, and no operative measures were undertaken till the third day, when the wound of entrance was repaired, the track sucked clear of clot and disorganized brain, and the missile removed from the left eye. Contrary to all expectations, he survived until the 10th day, and succumbed to a pneumococcus meningitis.

FIG. 663.—*Case* 100. 8-grm. unrubbed shell fragment.

Autopsy. — The track led across the base of the right temporal lobe, and passed through the sphenoid and ethmoid into the left orbit; both optic nerves were divided (*Fig.* 664). Extensive basilar meningitis.

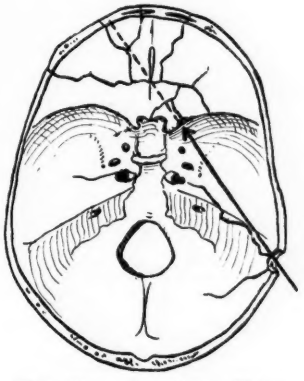


FIG. 664.—*Case* 100. Showing course of projectile.

It is possible that Dakin's disclosure of the antiseptic value of dichloramine-T when sprayed on the nasal mucous membrane, may make this an invaluable routine procedure in all basal fractures involving the cribriform plate.

B.—Auro-temporal Type of Cranio-cerebral Injuries.

In this type the percentage of fatalities was still higher, there being only one recovery. As in the foregoing, where infection extended from the nose, so here the chief danger lies in the extension of a septic process through a lacerated dura from the middle ear when the petrous bone has been seriously injured.

Case 101.—Pte. C. J. L. (Serial No. 118). **Multiple wounds Severe gutter wound of right auro-temporal region. Recovery.**

Admission, Sept. 20, 1917, 6 p.m.—Injured four hours earlier by high-explosive shell. Temporary unconsciousness. Severe headache. Considerable shock.

Wounds.—Multiple small wounds of right face and neck, with severe gutter fracture across lower temporal and zygomatic regions (*Fig.* 665); muscle lacerated; brain extruding. Lacerated wound of left arm. Compound fracture of left forearm. *X* rays show no missile.

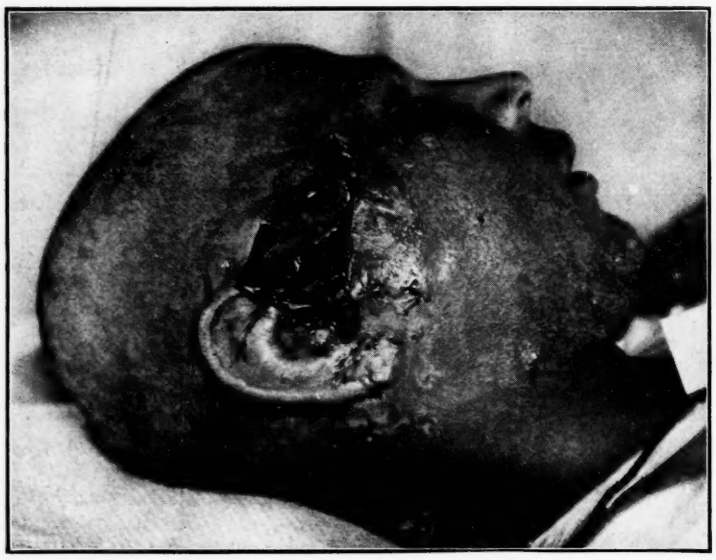


Fig. 665.—*Case* 101. Showing wound after preparation for operation.

Neurological Findings.—Marked nystagmus; apparent weakness (cerebellar?) of left side. Deep reflexes active, but equal. No mental disturbance.

Operation, 12 midnight (10 hrs.) Chloroform. Rapid repair of all wounds. Mere edges of temporal wound refreshed, with removal of fragments of squamous and petrous bones. Bleeding from extensive fungus controlled. No attempt at closure. Dichloramine-T. Gutta-percha dressing.

Post-operative Course.—Wound remained clean; highest temperature 101°: considerable discharge of sero-purulent fluid (cerebrospinal?) from ear for ten days. The necrotic surface of the fungating area finally became covered by the folding down of a flap of the torn temporal muscle. Discharged on 21st day: wound nearly healed.

Subsequent Report.—Oct. 21, No. 7 General Hospital.—No neurological symptoms; small granulating area; evacuated to England.

The Fatal Cases.—The following two cases are very similar to the foregoing, but with a less happy outcome.

Case 102.—Pte. W. S. (Serial No. 81).

Aug. 28, 1917.—Severe multiple wounds—head, forearm, thigh. Lying out 24 hours; poor condition. Lacerated wound, major type, across left temporo-aural region, completely dividing pinna and fracturing temporal and petrous bones. Makeshift repair under chloroform. Cheyne-Stokes breathing and final cessation

of respiration followed operation; breathing resumed after prolonged artificial respiration. Death on 3rd day: symptoms of meningitis.

Autopsy.—Deeper fragments of petrous bone penetrating dura; temporal lobe greatly contused; extensive leptomeningitis spreading from this area.

Case 103.—Pte. A. M. (Serial No. 21).

Aug. 2, 1917.—Rifle ball passing under helmet. Wound *en séton*, left temporal region; entry near external angular process; exit above mastoid. Considerable shock. Aphasia. Very difficult bloody operation; fractures of squamous and petrous bones, with deeply indriven fragments; bleeding meningeal; extensive laceration of temporal lobe. Partial closure.

Fungus cerebri with secondary hæmorrhage on 6th day. Enormous fungus gradually cleaned up, and temperature was normal till 20th day; sudden meningeal symptoms. Death on Aug. 27 (26th day).

Autopsy.—Purulent meningitis: septic track containing bone fragments leading through temporal lobe (*Fig.* 666). Lateral ventricle drawn out into hernia and opened. Ventriculitis. Septic thrombosis of lateral sinus and jugular bulb.

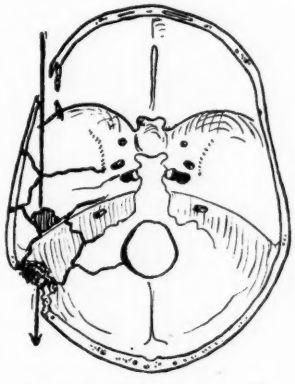


FIG. 666.—*Case* 103. Showing course of projectile.

The following three are examples of penetrating rather than gutter wounds of the region.

Case 104.—Dvr. J. E. J. (Serial No. 3).

July 25, 1917.—Wounded previous day. Admitted cold and pulseless, with double cranial wounds: (1) Supra-orbital; (2) Penetrating wound of right mastoid. Resuscitation therapy. July 26.—Signs of failing; Cheyne-Stokes respiration; choked disc of 2 D.

Operation.—Ether. Subtemporal decompression as last resort; right mastoid and petrous bones badly fractured, with embedded shell fragment, torn dura, cerebral extrusion, and sigmoid sinus thrombosis; wound left open.

Marked improvement for three days; bronchopneumonia; meningitis. Death at 6 p.m. July 30 (6th day).

Autopsy.—Extensive laceration of lower right occipital lobe containing indriven bone fragments; extensive disorganization of right cerebellar hemisphere. Mastoiditis; septic sinus thrombosis; meningitis of posterior fossa.

Case 105.—Pte. H. D. (Serial No. 155).

Sept. 28, 1917.—Lacerated wound over left mastoid, received previous day. Marked dizziness; nystagmus; some ataxia on right side. Operation showed depressed fracture of mastoid region, with injured sinus and punctured dura; wound left open. Early meningitis. Lumbar puncture (Gram-positive cocci in pairs). Death in 4 days.

Autopsy.—Mastoiditis; septic sinus thrombosis; purulent leptomeningitis; marked contusion of lower part of temporo-sphenoidal lobe.

Case 106.—Cpl. R. W. (Serial No. 34).

Aug. 3, 1917.—Penetrating wound through right external auditory meatus. Shock; resuscitation ward. Pressure symptoms; unconscious; pulse 112; respiration 44, Cheyne-Stokes; pupils dilated; right facial paralysis. *X* rays show missile in left cerebellum.

Operation, 3 p.m.—No anæsthetic. Flap procedure, with exposure both of temporo-occipital and right cerebellar regions; many loose fragments of petrous bone removed; internal ear opened; cerebellar dura tense; incised; lobe much lacerated; clots removed; missile not detected. Death at 8.30 p.m.

Autopsy.—Inferior temporal lobe and right cerebellum greatly pulped. Petrous bone almost entirely blown out; two large fragments had been driven with the

missile (*Fig.* 667) across the cerebellum just above the brachium pontis, and lay in the left cerebellar hemisphere (*Fig.* 668).

FIG. 667.—*Case* 106. Missile and loose fragments of petrous bone removed at operation.

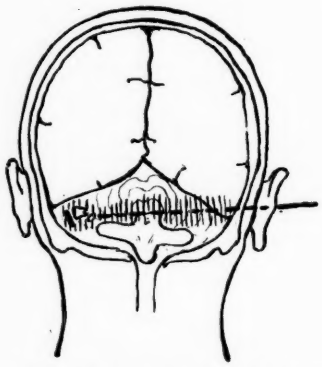


FIG. 668.—*Case* 106. Showing course and position of missile.

The last of these cases, though bizarre owing to the character of the secondary projectile, was typical of the group, in so far as the character of the fracture was concerned. The meningeal infection was in all probability from a direct implantation rather than due to an extension from an infected inner ear.

Case 107.—Pte. H. T. O. (Serial No. 82).

Aug. 28, 1917.—From resuscitation ward: history unobtainable. Condition bad; semi-conscious. Multiple wounds of right side of head, right elbow, right leg, all containing indriven foreign bodies. A cerebrospinal-fluid leak from deep gash over right zygoma. *X*-ray picture of head shows 13 missiles of varying character and size: one long hooked-shaped object embedded in petrous bone.

FIG. 669.—*Case* 107. Fragment of petrous bone and multiple foreign bodies.

Operation.—Chloroform. Excision of temporal wound; skull fractured by penetration of long brass object (part of equipment, *Fig.* 669) which has entered temporal lobe its full length; fluid escapes along this track; fragments of indriven squamous and petrous bones removed, exposing the entire inner ear; thorough drainage; repair of other wounds.

Aug. 30.—Cessation of fluid leak for 24 hours, with signs of meningitis. Ventricular punctures: 20 c.c. turbid fluid (culture: pneumococci). Aug. 31.—Lumbar puncture: turbid fluid (pneumococci). Sept. 1.—Exitus.

Autopsy.—Lines of fracture extend into petrous bone and orbital plate; temporal lobe pulped and hæmorrhagic; also right cerebellum; extensive basilar meningitis.

One recovery in seven cases, an 85·7 per cent mortality, can hardly represent the actual figures for this variety of cranio-cerebro-aural lesions. A trustworthy estimate cannot be based on figures so small. They serve, however, to point out the seriousness of injuries which involve an area that cannot be easily approached, and which harbour infections that can readily extend into adjacent torn meninges. Doubtless better methods of dealing with them can be evolved.

Group VIII.—WOUNDS TRAVERSING THE CRANIAL CHAMBER.

In its typical text-book form, as illustrated in the diagram (p. 563), few examples of cranial perforation occurred in the operative series. Victims of perforating wounds of the bipolar variety who survived to reach the casualty clearing station were usually moribund on admission, and later in the season, as the lines advanced and recovery of the wounded became still more delayed, few of them were seen.

FIG. 670.—*Case* 108. Wounds before operation.

As will have been observed, cases in which the missile actually traversed the cranial chamber, but stopped short of emergence, were recorded among the penetrating wounds in *Group V.* Cases, moreover, which with more reason might be regarded as true examples of perforating wounds, have been included with the cranio-cerebro-facial type of injuries in the preceding section.

Thus narrowed down, the present group contains only 5 cases, with but 1 recovery (mortality 80 per cent). The single recovery was an example of 'bow-string' perforation similar to that given in *Case* 103, though the level of injury was higher in the vault. The case follows.

Case 108.—Pte. C. B. (Serial No. 158). **Right temporo-parietal arc perforation. Operation. Recovery.**

Admission, Sept. 29, 1917, 5 a.m.—No history; semi-conscious; vomiting; shock. Resuscitation ward.

Wounds.—Entrance and exit, of seton character (*Fig.* 670); brain extruding. *X*-ray report: "Indriven bone fragments; no missile."

Neurological Findings.—Examination unsatisfactory, though evident weakness of left face, arm, and leg; tendency to conjugate deviation of head and eyes to right; deep reflexes brisk, equal, without clonus; no plantar response on left, normal on right.

Operation, 3 p.m. (*circa* 12 hours).—Novocain. Tripod incisions, with inclusion of scalp wounds. Severe fracture of temporo-parietal region, with broken fragments between wounds of entrance and exit. Temporal lobe greatly contused and hæmorrhagic, with bleeding afresh from torn Sylvian vessels on dislodging bone fragments; vessels secured with clips. Disorganized brain tissue sucked and irrigated out. Closure without drainage.

FIG. 671.—*Case* 108. On first dressing.

FIG. 672.—*Case* 108. On discharge

Post-operative Course.—Rapid improvement in general condition. Left homonymous hemianopsia disclosed. Focal seizures of face and arm on 4th day. Continued tendency of head and eyes to right deviation. Perfect wound healing (*Figs.* 671, 672). Slow improvement in palsy of face and arm. Evacuated Sept. 9 (11th day).

Subsequent Reports.—Oct. 10, No. 18 General Hospital.—General condition good. Evacuated to England. Nov. 5, No. 2 New Zealand General Hospital.—Slight occasional headaches. Paresis of left face and left half of tongue. Sluggish mentality. Boarded as unfit. No later report.

The Fatal Cases.—Most of these were subjected to very cursory procedures, which, however, necessitate their inclusion in an operative series. It is extraordinary how long may be the period of survival if the bulbar centres have escaped and pressure phenomena are not severe. One cannot abandon

these severe cases to their fate without some effort toward surgical cleanliness, if nothing else.

Case 109.—Pte. H. N. (Serial No. 28).

Aug. 1, 1917.—Unconscious; no history; vomiting; pulse 120. Perforating wound, presumably rifle ball; entrance right parieto-frontal, exit left supra-orbital region; bleeding brain extruding from each wound (*Fig.* 673).

Operation.—Temporizing repair of major wound of exit, with control of hæmorrhage; partial closure. Death in 6 hours. No autopsy.

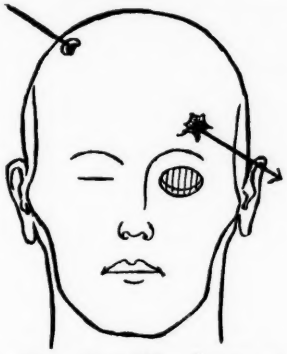


FIG. 673.—*Case* 109. Course of traversing missile.

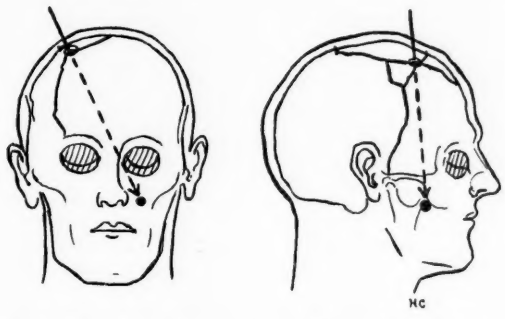


FIG. 674.—*Case* 110. Course of traversing missile.

Case 110.—Pte. F. B. (Serial No. 133).

Sept. 20, 1917, 6 a.m.—Irrational; noisy; fighting; no history obtainable; good general condition; pulse 60. Wound of entrance, right fronto-parietal; brain extruding. Shrapnel ball in right maxilla. Compound fracture of left arm. Extreme proptosis both eyes; nasal bleeding. Morphia; temporizing dressings and Thomas splint. Sept. 22.—Same condition; marked escape of cerebral substance; suction treatment of track, with removal of large amount of disorganized brain and clots. Sept. 24.—Slight operative repair of entrance wound, with removal of bone fragments, and catheter drainage. Death on Sept. 25, 3 p.m.

Autopsy.—Right parieto-frontal entrance wound, with far-reaching meridional fissures (*Fig.* 674). Exit wound through greater wing of left sphenoid; track continues into maxilla, where shrapnel ball is lodged under mucous membrane of throat. Septic meningitis.

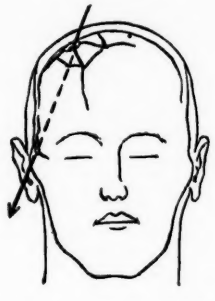


FIG. 675.—*Case* 111. Course of traversing missile.

The long-drawn-out course of some of these serious wounds, when left to pursue their own way, is shown by the following example.

Case 111.—Pte. W. I. R. (Serial No. 182½).

Oct. 11, 1917.—Admitted with history of lying out for four days. Conscious. Temperature 101·8°. Condition very poor. Multiple wounds: (1) Perforating in arc of right parieto-temporal region (*Fig.* 675), with brain extruding; (2) Perforating of right shoulder.

Operative repair of cranial wounds; badly infected gassy brain; temporal lobe completely disorganized (culture: *B. perfringens* and staphylococci); no attempt at closure. Subsequently large amounts of foul cerebral tissue escaped and large hernia formed. Survival for three days.

Autopsy.—Disorganization by encephalitis of almost entire right hemisphere; gassy odour.

In the following instance, as in the cases in *Group VI*, the ventricle was traversed by the missile in its course.

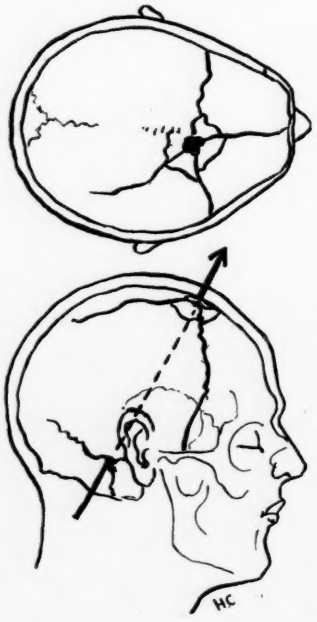


FIG. 676.—*Case* 112. Course of traversing projectile.

Case 112.—Pte. F. S. (Serial No. 188).

Oct. 12, 1917.—Semi-conscious; aphasic; no story obtainable. Good general condition. Wound of entrance, left mastoid; exit near mid-vertex (*Fig.* 676); brain extruding from both. Complete right hemiplegia.

Conservative operation under novocain, with catheter suction of disorganized tissue and clots from track, reducing tension. Dichloramine-T. Death on following day.

Autopsy.—Large extradural clot; widespread meridional fissures from wound of exit. Track of projectile passes directly through ventricle, which contains pyoserous fluid and indriven bone fragments.

Justice, in this brief section, has hardly been done to these traversing wounds. As the season progressed, the conditions of the terrain became such that few with wounds of this type survived to be brought back, and those who did had well-established infections. Under better conditions there should be a much higher degree of recoverability from perforating wounds than these few illustrations would indicate.

Group IX.—BURSTING FRACTURES WITH WIDESPREAD CEREBRAL CONTUSION.

In this, the last, group have been placed certain cases of major severity in which diffuse cranial fractures are associated with extensive and widespread contusions of the brain. They represent a type of injury which can be best relieved by a properly conducted cerebral decompression.

Massive fractures of the skull may occur, indeed often occur, without actual laceration of the scalp, and in fact there are certain varieties of crushed skull which have led to the assumption that some of these injuries may be due to the diffuse transmission of a blow from a heavy projectile through the well-fitting band of the helmet. Grave accidents, however, from being buried under heavy falling objects are so common in present-day warfare, that one must be cautious in attributing to a projectile itself a possible secondary effect of the explosion; and the majority of such patients are too profoundly unconscious on their admission to give any history, and usually have complete amnesia of the occurrence in the event of recovery.

Among the 10 cases in the series which have gravitated to this group, there were 5 fatalities (mortality 50 per cent). This fairly high percentage of recoveries does not really represent the grade of case which the group was intended to contain, for a number of surgically treated fractures, largely basilar in type (three), have come to be included for lack of a more suitable

group in which to put them. Other basilar fractures which recovered without operation or following a lumbar puncture are incorporated among the non-operative cases.

Many examples of extensive egg-shell injuries, with fissures which radiate from a local impact or penetration made by a missile, have been recorded in the preceding sections. Fractures of this kind, in which the indications for local investigation are clear, are of quite a different order from those here considered.

The following two cases exemplify the type of injury under discussion.

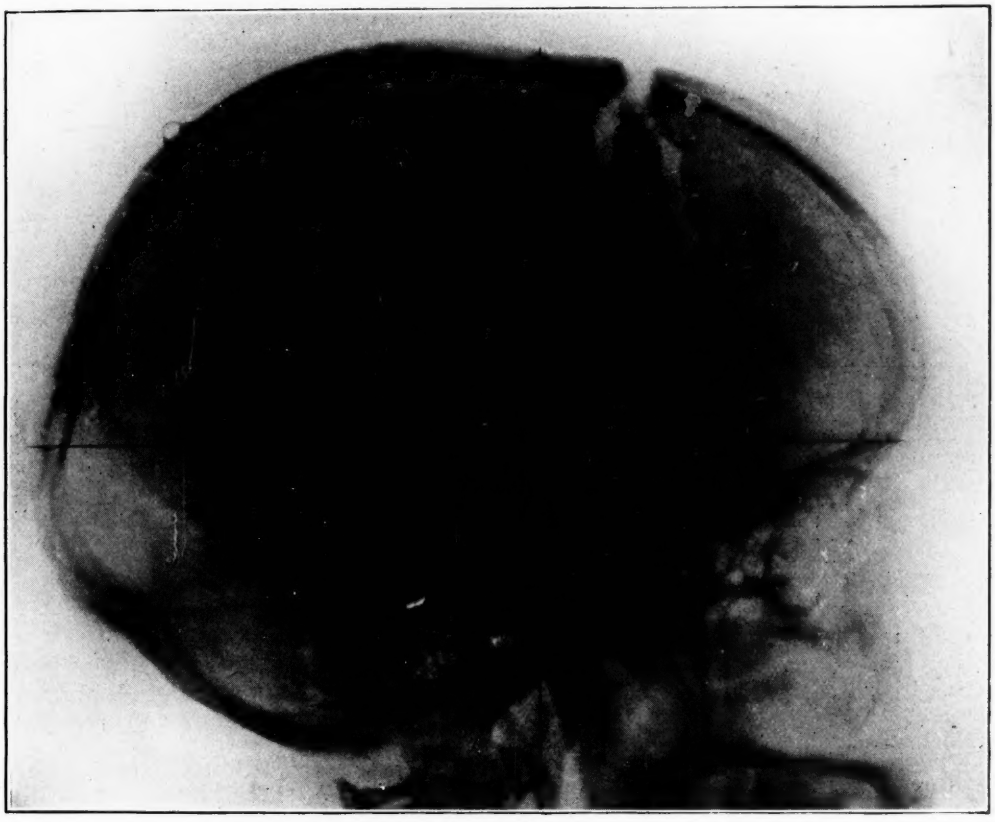


FIG. 677.—*Case* 113. Radiogram of bursting fracture.

Case 113.—Pte. W. W. (Serial No. 46). **Multiple wounds. Extensive bursting fracture of skull, with diffuse cerebral contusion. Subtemporal decompression. Recovery.**

Admission, Aug. 12, 1917, 11 a.m.—No history. Cold and in collapse ; stuporous. Resuscitation ward. Became restless ; tossing ; periods of great activity requiring restraint, alternating with quiet periods. Vomiting ; pulse 60.

Wounds.—(1) Multiple lacerated wounds of thigh ; (2) Perforating wound of right arm ; (3) Small punctured wound of scalp in right parieto-occipital region. *X* rays show massive fracture of skull, with diastasis of sutures (*Fig.* 677).

Neurological Findings, 5 p.m.—Can be roused to restlessness by supra-orbital pressure ; apparent paresis of left arm and leg, though he moves all extremities.

Right pupil larger than left. Reflexes all in normal limits. 5.30 p.m.—A Jacksonian seizure, beginning in left face, to arm and leg. Fundi show considerable œdema, with obscuration of cups and nasal margins.

Operation, 6 p.m.—Right subtemporal decompression. Exposure of extensive linear fractures; no bony depression; broken subtemporal plates of bone removed, disclosing very tense, discoloured dura. Dura incised, with partial evacuation of large subdural clot; exposed and protruding brain very tense, and everywhere of a deep cherry-red colour. Closure in layers without drainage.

Post-operative Course.—Became increasingly restless, requiring morphia. Quieted and began to regain consciousness on the 4th day, when he took first nourishment by mouth. Usual wound-healing (*Fig.* 678). By the 12th day he became quite rational, and would obey ordinary commands. Somewhat silly in mental attitude. Persisting weakness of left arm and face, with exaggerated reflexes. By

FIG. 678.—*Case* 113. Subtemporal decompression: wound on tenth day.

time of discharge, Aug. 29 (17th day), was well oriented and in good physical condition, though pulse was somewhat slow and temperature tending to subnormal. No headaches at any time.

Subsequent Reports.—Sept. 1.—Good condition; evacuated to England. Dec. 12, King George Hospital.—Mental state much improved. Discharged permanently unfit. Feb. 22, 1918 (by letter).—At home; inclined to be giddy; refuses to wear his aluminium cap; wishes to get back to the colours. Doubtless shows signs of mental deficiency.

The following case, somewhat similar in character, is of interest in that the patient, having no external wound, was sent down with the diagnosis of 'shell shock.'

Case 114.—Pte. J. P. (Serial No. 66). **Massive fracture of cranium, with cerebral contusion. Decompression. Recovery.**

Admission, Aug. 19, 1917, 12 midnight.—No history obtainable. Unconscious; restless; slight bleeding from left ear; pulse 64.

On examination, no external wound was found; marked œdema and ecchymosis of eyelids. Crepitus elicited by pressure over left side of head. *X* rays show bilateral massive fracture of the skull, with diastasis of fronto-parietal sutures

(cf. *Fig.* 679).* Patient can be roused by supra-orbital pressure; mutters incoherently; no evidence of paralysis. Fundi injected, slightly œdematous. Deep reflexes barely obtainable on left; lost on right; normal plantar responses.

Operation, 9 p.m.—Right subtemporal decompression. Linear fractures disclosed, crossing temporal bone. Tense dura opened, showing widespread contusions, with uniform reddish discoloration of brain. Closure.

Post-operative Course.—Began to regain consciousness on 2nd day: after this made very rapid recovery, though mentality was somewhat wandering for several

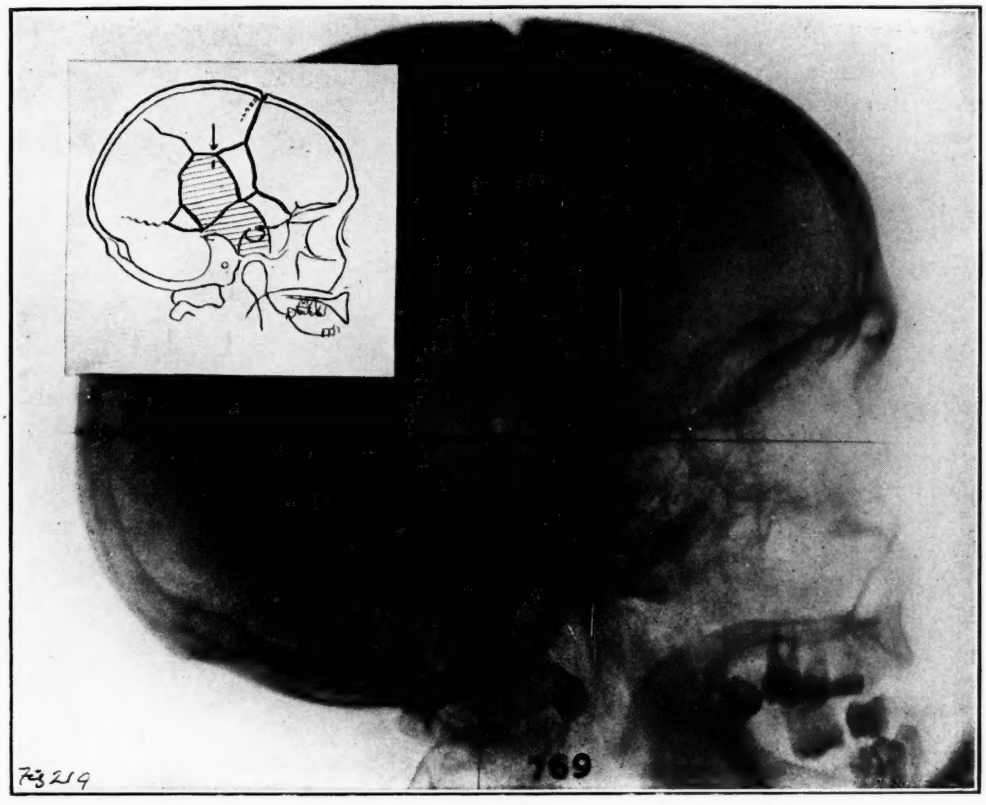


FIG. 679.—*Case* 114. Radiogram tenth day after operation, showing area of decompression. Linear fractures largely obscured: shown in remarque. Silver clip (arrow) on meningeal branch at dural margin.

days. No headaches; usual wound-healing (*Fig.* 680). Temperature and pulse tending towards the subnormal. Evacuated Sept. 2, in excellent condition.

Subsequent Report.—Feb. 15, 1918 (by letter from wife): Has made a good recovery, though has headaches at times. Is classed B 2; is with a labour company.

The question might naturally be asked, in cases of this kind, whether, after all, the decompression is essential, and whether *lumbar puncture* might not answer the same purpose, for we are not dealing with a permanent source

* This figure is given to show the *x*-ray appearance of a silver clip. I have learned of an operation being performed in England to remove one of these clips, under the apprehension that it was a piece of projectile, and doing harm.

of pressure like a tumour, but with a self-limiting process, provided the medulla is not implicated. It is well known that in these conditions of cerebral contusion the brain shows a marked tendency to take up fluids and become œdematous, and oftentimes the cerebrospinal spaces contain an excess of blood-stained fluid —even the subdural space, which under normal conditions contains very little fluid. It has become a matter of common observation that some measure of

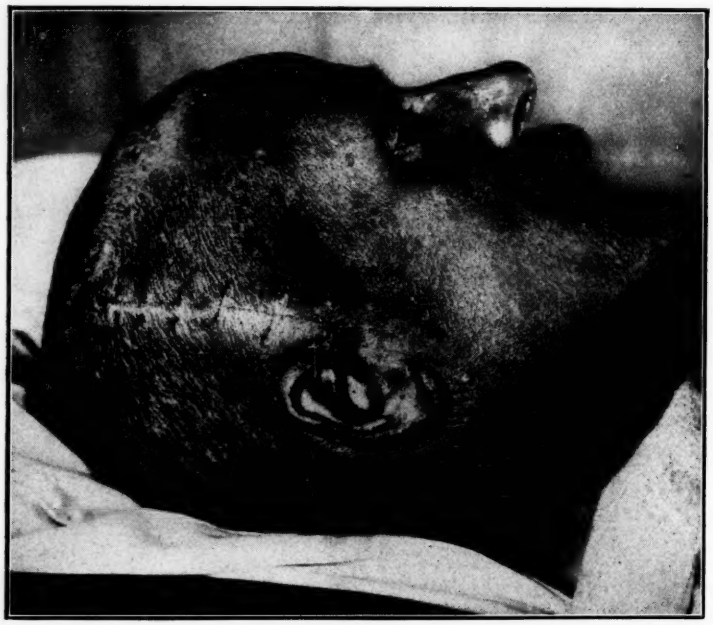


FIG. 680.—*Case* 114. Subtemporal decompression: wound on tenth day.

relief can be afforded by the withdrawal of fluid by the lumbar meninges. However, when the brain itself is greatly contused and swollen, the mere withdrawal of 20 or 30 c.c. from the cerebrospinal spaces is but a temporizing measure. This can be well appreciated by observing the effects of a lumbar puncture on a decompressed patient during the early days, when there is protrusion of the tense brain through the defect; for though the protrusion under the temporal muscle promptly subsides on withdrawing the fluid, the former degree of tension is regained in a very short time, and not infrequently the protrusion seems to return with a higher degree of tension than before. Hence these punctures, even if repeated daily, actually afford but a very brief period of relief.

The operation for a subtemporal decompression is not always easy, and requires experience, facility, and a special type of rongeur forceps, if, without undue injury to temporal muscle, an opening of sufficient size is to be secured. However, there is little doubt but that in many cases a much more prompt return of consciousness is afforded by this measure than would otherwise occur, and in some cases it may be a life-saving procedure.

The following experience affords an illustration of some of these points.

Case 115.—Rfm. L. H. (Serial No. 48).

Aug. 12, 1917.—Admitted unconscious, with the diagnosis of 'concussion'; a small abrasion was present over the right frontal eminence. *X* rays showed a massive fracture of the skull, with fissures radiating from the frontal area.

Patient was admitted in the care of a colleague, who for three successive days performed lumbar punctures, withdrawing as much as 36 c.c. of port-wine-coloured fluid. Consciousness was not regained, and the man continued restless, incontinent, and was at times violent.

On Aug. 15 the pulse became slowed, and he passed into a stupor. He was transferred to us for a subtemporal decompression. On the day following the operation he showed very great improvement; full consciousness returned by the second day; and on Aug. 21 he was evacuated in good condition with practically clear mentality.

Though unfit for further military service, and discharged Nov. 3, he has made a good recovery, barring some tendency to headaches.

The term 'cerebral decompression' is often very loosely used—not to say abused. The mere making of a hole in the skull around a depressed fracture, with wide opening of the dura to relieve pressure of a local contusion or infection, led to many disasters earlier in the war; and it is much better to restrict not only the term, but the procedure, as in the case of tumours, to measures directed toward the relief of pressure carried out in clean fields under temporal or suboccipital muscles, with immediate secure closure of the overlying structures.

At best, however, a subtemporal decompression is not a measure of very wide scope in the cranio-cerebral injuries of warfare, though, as we shall see in the histories to follow, it would have offered two or three of the patients their only chance.

The Fatal Cases.—The five in this group may be briefly recorded.

Case 116.—Pte. C. B. (Serial No. 182).

Lying-out case. Very extensive and infected multiple wounds of back, with fracture of scapula and ribs. Wound of right frontal area, with massive cranial fracture.

Operation.—Temporizing elevation of depressed cranial bone plates; free opening of badly infected extensive wounds of back: Carrel-Dakin treatment. Death from gas infection the following day.

Autopsy.—Extensive fractures of skull; the dura intact; widespread cerebral contusion.

The two following cases were suitable ones for subtemporal decompression, and, had it been possible to determine the side of the large extravasation in each, a chance of recovery might have been afforded, and in the second case the pneumonia possibly forestalled.

Case 117.—A German prisoner (Serial No. 103).

Aug. 16, 1917.—Semi-conscious; massive egg-shell fractures without depression, radiating from the occiput, where is a large infected scalp wound three days old. Attempted local operation under ether, with complete repair and closure by plastic flaps. Wound infected (*B. perfringens*). Death in 24 hours.

Autopsy.—Extensive subdural clot over left hemisphere, the posterior half of which is completely pulped and disorganized to the ventricle.

Case 118.—Pte. F. H. W. (Serial No. 174).

Oct. 5, 1917, 11 p.m.—Irrational; violent; semi-conscious. A ragged wound of vertex. No *x*-ray examination possible.

Operation.—Chloroform. Repair of local wound, disclosing egg-shell fractures without depression; bone removed; dura tense and discoloured; not opened. Lumbar puncture: 30 c.c. bloody fluid. Deglutitory difficulties. Death on 7th day from inhalation pneumonia, with terminal rise in temperature (*Fig.* 681).

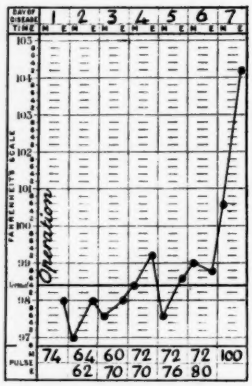


FIG. 681.—Temperature chart of *Case* 118.

Autopsy.—Far-reaching meridional fractures; subdural clot over entire left hemisphere; cerebral contusions; no meningitis. Bilateral bronchopneumonia.

Case 119.—Pte. A. M. (Serial No. 100).

Sept. 14, 1917.—No history obtainable; semi-conscious; aphasia; right hemiplegia. Multiple wounds of arm, leg, and head. Massive fracture of skull, with missile embedded in scalp of vertex.

Operation.—Chloroform. Subtemporal decompression, disclosing large subdural clot and contused brain with bleeding vessels. Death on 3rd day from pneumonia, after 24 hours of marked improvement in cerebral symptoms.

Autopsy.—A typical bursting fracture completely encircling skull in coronal plane. Longitudinal-sinus thrombosis; hemispheres widely contused and hæmorrhagic. Bilateral hepatization of both lungs.

Case 120.—Pte. A. L. (Serial No. 197).

Oct. 19, 1917.—Transferred for decompression by a colleague after 48 hours in resuscitation ward. Profoundly unconscious; pulse 110; temperature 103°. Extensive contusions of head and face. Choked disc.

Operation.—Subtemporal decompression; no anæsthesia required. Marked improvement in 24 hours; temperature lower. By 2nd day consciousness partly regained. Bad cough with profuse expectoration; taking nourishment well. On 3rd day pneumonia, with abrupt rise in temperature (*Fig.* 682), and death.

Autopsy.—Brain œdematous and ecchymotic; extensive pulmonary hepatization.

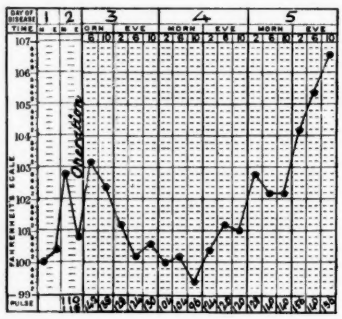


FIG. 682.—Temperature chart of *Case* 120.

It will be noticed that these patients were for the most part refractory, and threatened with respiratory complications due to their compression—a combination which practically prohibits an operation under local anæsthesia with primary morphinization. It is possible that the inhalation narcosis may have had some predisposing effect in the causation of the pneumonia from which three of them died, particularly when one considers how prevalent some form of pulmonary disorder is among the wounded, either as a chronic bronchitis or an irritation from some degree of exposure to gas fumes. The fatalities, however—one of them after a six-days-free interval—bring up another matter on which a caution should be expressed. There is a general tendency on the part of orderlies and nurses who may be unfamiliar with head cases, or uninstructed as regards this particular point, to attempt to feed semi-conscious patients. A typical bronchopneumonia, brought about by misdirected efforts to administer fluids to patients with inactive swallowing reflexes, is a far from uncommon sequel. It is a good rule to keep every stuporous patient in a semi-prone position, and trial feedings should never be first attempted while they are lying on their backs.

THE UNOPERATED CASES.

The record of any series of cases such as constitute the present study would be incomplete without an enumeration of the unoperated cases, with particular reference to the more severely wounded from whom surgical intervention has been withheld. The percentage of such cases must vary considerably according to many circumstances.

It was found from a study of the hospital admission and discharge books for the first fourteen days, including one 48-hour period of considerable pressure, that an average of 50 per cent of all the head cases were immediately cleared after dressing and recording, without being subjected to further examination; and that during the rush period of two days, 85 per cent were thus promptly forwarded to the base. This of course implies that the supposedly more serious cases were alone retained. Whether this is wise from a military standpoint is a matter for others to decide, and customs may change in this respect; but the fact must be taken into consideration in so far as it influences surgical statistics. In slack periods, when no such selection is made, the surgical results for many reasons are much better.

Another factor greatly affecting the character of the wounds and the condition of the cases admitted concerns the bearer parties: the more daring they are and the more quickly the wounded are brought in, the more lives will be saved—but, contradictory as it may seem, the higher will be the hospital death-rate, for more desperately wounded men will reach the casualty clearing station alive than when a corps less energetic and less indifferent to danger is in the field. This applies to cranio-cerebral no less than to abdominal or thoracic wounds.

Then, too, during this particular period of service, with a line of battle advancing and a stationary casualty clearing station, the interval from the reception of the wound to the time of admission became progressively greater, so that fewer of the more immediately serious types of cranial injury survived the average of ten to twelve hours required to bring them in. As an offset to this, those that were brought in were almost certain to have an infection already established. These and other modifying factors must be taken into consideration in judging statistics of any given hospital, in any period, for any particular variety of work.

The 31 cases which, assigned to the writer's team, were not operated upon, fall in three categories:—

1. *Those in which an operation was unnecessary or inadvisable* (11 cases).—An operation may be uncalled for for various reasons. Among the 11 cases, all of which recovered, were 3 examples of extensive cranial fracture without depression, overlain by lacerated scalp wounds too large to close, and whose healing processes could not be expedited by operative measures; such wounds, after being merely scrubbed under local anæsthesia, were Carrelized, and left to heal by the slow process of granulation until they could be skin grafted, and not even were their ragged margins excised. In 2 other cases the unexcised scalp wound was left open owing to infection: one of them was subjected to a secondary craniotomy on reaching the base. There were 3 examples of penetration by a minute missile, with operation

withheld owing to absence of symptoms. There were 3 bursting fractures involving the cranial base, which were treated simply by lumbar puncture.

2. *Those in which operation offered nothing, owing to the extent of the lesion or the patient's general condition* (10 cases).—The 10 cases in which the condition was regarded as hopeless were cases which, if operated upon, would have fallen in *Groups VII, VIII*, or *IX*. There were 2 severely wounded men with a large part of the skull blown away, who quickly succumbed. There were 4 penetrating wounds—one with extreme explosive effect, with elevation of a large cranial gap (*Fig.* 683); the patients survived but a short time. There were 4 examples of extensive bursting fractures, the patients being practically moribund on admission, with advanced pressure phenomena and early respiratory failure.

FIG. 683.—Showing explosive effect of fronto-parietal perforation with elevation of large section of skull.

3. *Those regarded as possibly operable, but in which death occurred before reaching the table* (10 cases).—These cases do not fall in the operation group, though they might have done so had not death intervened. To some, reference has already been made (e.g., *Cases* 3 and 83). The borderline is a very narrow one, and perusal of the fatal cases in the operation series, brief clinical notes of which have been given, will show that desperate chances were often taken to revive cases approaching the terminal stages of compression (e.g., *Case* 78). There is no justification in withholding operation from those unfortunates for whom a prolongation of life would appear to be undesirable; no tribunal is capable of passing such judgement, and unexpected recoveries with unimpaired mental faculties sometimes follow what appear to be the most extensive cerebral injuries.

THE OPERATIVE PROCEDURE.

This has been described in sufficient detail in a recent communication.* As stated, the purpose of the present study is merely to put on record, for the sake of future comparison, the clinical results secured. Some passing comment on these operations in general may, however, not be out of place.

* "Notes on Penetrating Wounds of the Brain," *Brit. Med. Jour.* 1918, Feb. 23.

It is not without interest that early in the war many surgeons who dealt largely with cranial injuries came to advocate the immediate excision and closure of scalp wounds overlying fractures with penetration. They were doubtless forced to this alternative, more because of the unhappy consequences of a fungus cerebri in case the wounds were left open, than through any broad conception of the general principles of primary wound suture, which was then discountenanced.

We are now aware, largely through the pioneer work of French military surgeons, that so far as possible during the few hours before infection takes place, practically all wounds should be given the chance of union by primary suture. The necessity of the most detailed preliminary *débridement* of the wound, as emphasized by Depage, Duval, Le Maitre, and others, before these immediate closures are attempted, is making its way as a matter of fundamental surgical, as well as of military, importance.

These principles apply no less to cranio-cerebral wounds than to those of the extremities; but with the former we are confronted by anatomical difficulties which do not pertain to wounds elsewhere, for in the brain one cannot dissect along the track and lay the part open to inspection as can be done with the majority of wounds in other parts.

The many failures in the past in the primary suture of cranio-cerebral wounds have been due, on the one hand, to the prevailing idea that there was something peculiar about injuries of the nervous system which justified a long delay before operation—a delay which permitted a contaminated wound to become infected; on the other hand, in case the operation was performed in the first few hours after the injury, to imperfect methods of removing —together with other wound débris—the devitalized nervous tissue which makes a favourable soil for bacterial growth.

As generally practised, the cleansing of a contaminated cranio-cerebral lesion has usually consisted in the excision of the scalp wound, piecemeal removal of the bony lesion, enlargement of the dural opening, extraction so far as possible, usually with the insertion of a finger, of the indriven fragments of bone or metal, and closure by sliding or replacing a flap of scalp over the area of the wound. This has been the practice, not only in the early hours when the wound is merely contaminated, but later on when infection has become established.

That 50 per cent of wounds with dural penetration have recovered under these circumstances speaks well for the natural resistance of the brain to mild grades of infection. But if from these past computations the trifling dural punctures like those incorporated in *Group III* had been excluded, and only the cases of actual exposure with contamination of the brain and meninges had been considered, the mortality would in all certainty have been found far higher.

In the technique which has come to be utilized in the later cases in this series, and which is capable, doubtless, of further development in many directions, not only the scalp wound but the contaminated cranial wound as well have been excised *en bloc*. Subsequently, by the aid of alternate irrigation and suction through a soft flexible catheter inserted in the track, the clots and devitalized brain substance are painstakingly removed, the fragments

of bone detected by the catheter are picked out by delicate forceps, and the projectile in as many cases as possible is extracted by the magnet. In short, the same principles of *débridement* utilized so successfully for wounds elsewhere, have in their essentials been adapted to wounds involving the brain.

The criticism has been made that these performances entail too great an expenditure of time and are impossible to carry out in periods of rush; but this is no more true of cerebral wounds than of other deep wounds in which one may wish to secure primary union. In the long run it is far better in an advanced hospital to get one successful primary closure of a penetrating wound of the brain, and to send two others to the base as yet untreated, than to do three incomplete operations in the same period of time, with the probability that all three wounds will break down, and at best undergo subsequently at the base the tedious and uncertain course of secondary wound-healing over an exposed and fungating brain.

There is much difference of opinion as to where these operations should be done, but in view of the fact that the majority of deaths occur from meningitis or encephalitis, it would seem that a forward area is desirable, even should it be admitted that in head wounds infections appear to be slower in taking hold than in the case of lacerated wounds of the muscular extremities.

THE RESULTS IN GENERAL.

As recorded in the opening paragraphs, as our experience increased, the mortality of the 133 wounds with dural penetration was reduced from 54·5 per cent for the first 44 cases, to 28·8 per cent for the 45 cases in the third period—this in spite of the fact that with the advancing line of battle the interval between the reception of the wound and the patient's admission averaged at least six hours longer in the last few weeks of the service. Other factors, in addition to the thorough treatment of the track, doubtless contributed to these improved figures—among them, the routine employment of local anæsthesia, as advocated particularly by Colonel Gray and by De Martel; detailed individual attention to the often complicated post-operative dressings was another element of no little importance.

A tabulation of the 71 fatalities in the operation series taken as a whole, shows that 12 deaths were due to intercurrent causes—to multiple wounds elsewhere, to pneumonia, gas poisoning, and so on; 16 were due to acute intracranial complications—hæmorrhage, extensive lacerations, or compression phenomena arising before the period of sepsis; whereas 43 were due to, or at least associated with, an intracranial infection—meningitis in 14, ventriculitis in 12, encephalitis—usually from gas infection—in 9, and abscess in 8.

Naturally, many of these conditions more or less overlapped: a severely traumatized case might finally die from inhalation pneumonia; an abscess might break into the ventricle; an infection of the brain finally spread both to ventricle and meninges. The figures, however, record the outstanding feature of the post-mortem findings in each case. Their chief significance lies in the overwhelming predominance, even in a forward area, of the infections over all other causes of death; and this would be equally true of wounds of any

other part of the body similarly treated—namely, by closure of the skin over an incompletely cleansed track.

The clinical histories of the 219 operation cases have shown clearly that a large number of the recorded fatalities were avoidable—not only by the employment of a still more perfect technique, but by its more prompt application. The bad repute of cranio-cerebral operations from the standpoint of infection is, without question, largely due to delay—delay in transit, which may be unavoidable; unnecessary delay after admission, which often is avoidable.

So far as our records made it possible, the time intervening between the reception of the injury and the operation has been given with the operative note for each case, and it will have been observed that few were operated upon within the first 12 hours, and many after a 24-hour interval. This means that all of the contaminated wounds had become infected, some most seriously, before they reached the operating table.

The delay in many instances was due to an unnecessarily prolonged sojourn in the ward given over to the resuscitation of the seriously wounded. This period, I think, so far as head cases go, can be eliminated, for the body warmth can be restored and fluids administered during the course of an operation on the head under local anæsthesia, as well as in a special ward. The effects of cerebral contusion are often confused with shock, and the condition of many of these head cases does not improve until trepanation makes possible the evacuation from the intracranial chamber of the clots and pulped brain which are the occasion of pressure symptoms.

Though a period of a year or two must elapse before one can speak of the actual end-results of the 152 cases which were evacuated after operation, the subsequent reports, as may be gathered from the notes appended to the case-histories, have been most encouraging.* The statement has been made that, earlier in the war, 45 per cent of all cases trephined at casualty clearing stations subsequently died at the base: this refers, of course, to a period when cases were forwarded immediately after operation.† In the present series, the more serious cases were retained an average of twelve days, and,

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* The home address of all the patients was taken, and it has been possible by direct correspondence or through Medical Research Committee inquiry cards to trace all of them with the exception of a few colonials. I labour under the impression that most of these cases after reaching England are kept too long in hospitals or convalescent depôts for their best good. In many instances they have been retained apparently for the purpose of bone grafting or of fitting metal plates in the small cranial defect, or for the making of plates of one kind or another which are to be worn in the cap. These measures cannot be of very great service to many of these patients. They should be restricted to the cases with large pulsating defects accompanied by dizziness and discomfort on stooping or exertion.

† Taken as a whole, the mortality for the entire series was 32·4 per cent, or, excluding the 22 scalp wounds, 35·5 per cent. In contrast with these figures for a casualty clearing station, certain figures may be given for cranial operations performed at the base, which at first blush might seem to favour these delayed procedures, did one not realize the elimination which had been taking place in process of transit from the line of battle.

During a nine months' service in two base hospitals with the B.E.F., members of the writer's unit have made careful clinical records of 147 head wounds out of a possible 200 cases—the unrecorded cases having been those of minor nature and without special clinical interest. Of the 147, 34 were scalp wounds, recorded because of concomitant cerebral

as recorded among the fatal cases, only 4 deaths have occurred among the number evacuated, 2 at the base and 2 in home hospitals (*Cases* 17, 59, 66, 76).

The careful studies by Sargent and Holmes of a series of 1239 cases, and by Tuffier and Guillain of a series of 6664 cases which had recovered after trephining, have shown that late sequels, such as epilepsy, insanity, delayed abscess, crippling paralyses, and other residual infirmities, are far less common than had been anticipated. This may serve as an additional source of encouragement for those called upon to operate on these difficult neurological cases.

There is every reason to believe that by earlier operations, and by further improvements in technique along the lines of painstaking aseptic surgery, the accepted high mortality of cases with dural penetration can be very largely cut down; and if this long presentation of a single series of cases can help to bring this about, by serving as a score against which others working under similar conditions may successfully compete, it will have served its purpose.

The writer has received help from many sources in the preparation of this paper, but he is under particular obligation to the Medical Research Committee for permitting Sergeant Maxwell to give time for the making of many of the illus rations. He regrets greatly that he has not had access to the abundant literature on the subject, for this has prevented his making suitable reference to the writings of others who may have made corresponding analyses of a series of cases operated upon under similar circumstances.

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symptoms. Eliminating these scalp wounds, all of which recovered, there remain 113 cases, which fall in *Groups II* to *VI* as follows: *Group II*, 41; *Group III*, 17; *Group IV*, 16; *Group V*, 35; *Group VI*, 4. The more serious types of injury, such as one encounters further forward, were entirely wanting.

Taken together, the total mortality at the base for the 113 cases has been 10·6 per cent: 85 cases had been operated upon before adn ission, and several had to be re-operated upon for abscess, with 6 fatalities (mortality 7 per cent); 37 *received their primary operation at the base, with only* 6 *fatalities* (*mortality* 16·2 *per cent*), i.e., less than half the mortality percentage of the writer's casualty clearing-station series.

BONE GROWTH AND BONE REPAIR.*

By Professor ARTHUR KEITH, F.R.S.

LECTURE I.

THE FOUNDATION OF OUR KNOWLEDGE OF BONE GROWTH BY DUHAMEL AND HUNTER.

Sometime in the summer of 1736, a calico printer of the City of London entertained to supper John Belchier, a promising young and inquiring surgeon, and, all unwittingly, introduced him at the same time to a method of unravelling some of Nature's greatest secrets. The method to which Belchier was thus introduced was that of vital staining, one which picks out certain elements of the body by distinctive colours while they are still living. The calico printer was an economical man, and used the madder-soaked bran from his dye-vats to feed pigs. The pigs he used to feed his friends. It was a joint of this madder-fed pork which was placed before the young surgeon, then in his thirtieth year and just elected to the staff of Guy's Hospital. It was but natural that a young man, already a fellow of the Royal Society and a contributor to its *Philosophical Transactions*, should have his curiosity aroused by the ruddy colour of the bones of the madder-fed pork, and that he should resolve, on returning to his home, to make further inquiries before bringing this strange matter before the Fellows of the Society. He desired, first of all, to make certain that it was madder and no other substance which stained living bones, and hence he began to feed some of his fowls with madder. One cock, subjected to this treatment—fed by force, for fowls refuse food mixed with madder—died at the end of a sixteen days' course; the bones were stained, even those with the densest structure. Early in the autumn he made a communication to the Royal Society, which was subsequently printed in its *Transactions*.†

Having duly recorded this strange action of madder on bones, Belchier felt that his inquiry was finished, and left the matter there. The man who was to show that Belchier had discovered a means of unravelling the complex manner in which bones grow, was a remarkable French squire—Henri Louis Duhamel, Seigneur du Monceau—but of him more anon. For Belchier there was no problem of bone growth. His master and teacher, the great Cheselden, knew all there was to be known about bones—particularly so far as concerned those of the human skeleton. Bones "are covered by a fine membrane, which upon the skull is called pericranium, elsewhere periosteum. It serves for the muscles to slide easily

* Three lectures of a course on "The Anatomical and Physiological Principles underlying the Treatment of Injuries to Muscles, Joints, and Bones," delivered at the Royal College of Surgeons of England.

† *Phil. Trans.*, vol. xxxix, p. 287.

upon; it is everywhere full of small blood-vessels, which enter the bones for their nourishment." Bones "grow by the continual addition of this ossifying matter; they increase till their hardness resists a further extension; and their hardness always increasing while they are growing, the increase of their growth becomes slower and slower until they cease to grow at all." "In a fractured bone, in which the same kind of matter which ossified the bones at first, is thrown out from the broken ends, there is formed a mass of callous matter."* It is extremely important that we should note these points: that periosteum was a vascular membrane which supplied nourishment; that bones grew like other tissues—by a natural filling up and expansion of every interstice; and that, when broken, the fractured ends threw out a mass of ossific callus. That was the state of knowledge as regards bones when Duhamel and Hunter commenced their investigations.

Our story now shifts from London to France—to the well-managed estate of Monceau, where Duhamel, a confirmed bachelor, and his maiden sister spent busy and studious days. Duhamel belongs to that rare type of man which is represented by Stephen Hales and Benjamin Franklin—men born with a natural aptitude to play the part of detectives amongst Nature's secrets. They wrung them from her by experiment. For Duhamel there was but one sure source of knowledge—observation and experiment. He had spent his youthful days in Paris as a student—a student of law; but he had attended Winslow's lectures, and at an early date had begun investigations relating to agriculture which brought him into touch with the Academy of Science and the foremost researchers of his time. At the age of twenty-seven he was elected a member of the Academy. We make his acquaintance when he was thirty-nine years of age, in 1739, when he made his first communication to the Academy, "Sur une Racine qui Teint les Os en Rouge." He was then living on his estate. A year or two before, Hans Sloane, President of the Royal Society, had drawn his attention to Belchier's paper. His curiosity was aroused, and following his usual custom, he submitted Belchier's observations to the test of experiment. He fed fowls, turkeys, pigeons, and pigs with madder, and found that their bones, and only their bones, were stained red; he noted that only certain parts of the bones were stained, and that the bones of young animals dyed more readily and deeply than those of old animals.

In his communication of 1739 he had really added very little to Belchier's observations. It was merely a preliminary note. His next communication appeared in 1741, and we see he had been hard at work. He had become interested in bones; he knew well how a broken twig became mended, and he wondered how repair was carried out when a bone was broken. He made experiments, and found that the periosteum in the neighbourhood of a fracture became greatly swollen, and served as the chief agent in producing the repairing callus. The lining medullary membrane, or internal periosteum, assisted. By feeding the subjects of his fracture experiments with madder, he could trace the formation of the newly-formed bone, and found that its chief source was the periosteum. He saw nothing to support the prevalent

* *The Anatomy of the Human Body*, by William Cheselden, 6th edition, 1741.

belief that the callus was produced by a 'juice' secreted by the broken ends of bones. He had now realized that the only bone which was stained red was that formed during the period of madder-feeding.

His communications of 1742 and 1743 show us that his further experiments had been attended by a great success. He had discovered an early mistake. If, after giving a course of madder food, and then a course of ordinary food, a pig was killed, he observed in his earlier experiments that nearly all redness had gone from the bones. He was thus led to believe that the stain was only temporary. But on laying such bones open, he observed his mistake—the madder-coloured layer was only covered and hidden by an unstained surface layer, laid down after the madder diet had been suspended. He found, by alternating a madder diet with an ordinary one, that he could obtain alternate red and white rings or layers on the circumference of the bone, the latest-formed layer or plate being on the surface of the bone immediately under the periosteum. Bone therefore grew as wood did—by the super-imposition of layer on layer or plate on plate; and the source of the new layers was the periosteum. The deepest stratum of the periosteum apparently served the same purpose as cambium did for growing wood. In this way Duhamel came to regard periosteum as the maternal tissue of bone; the osteogenetic function of periosteum is Duhamel's discovery.

He was faced by a great puzzle. Bone grew in thickness only by superficial additions laid down lamina upon lamina. He noted that the medullary cavity also kept enlarging as the bone grew; in the pig's tibia the cavity kept increasing until the animal was six months old. He could conceive only one way possible—namely, that as the superficial layers were laid down, there was also an expansion of the shaft-cylinder as a whole, an expansion which enlarged the medullary cavity. He sought to prove the truth of his theory by a new kind of experiment—one he had practised on growing branches. He encircled the shafts of growing bones with rings of silver wire, and in the course of time found, as he expected, that they had cut their way into the medullary cavity. He believed that such a result could be obtained only by an expansion of the shaft. We shall see presently how John Hunter explained the result of such experiments.

Duhamel was familiar with the fact that bench marks cut on the stems of trees maintained a constant level; growth in the trunk did not alter the level. He applied a similar method to bone; he cut 'bench marks' on the shafts of growing bones, by drilling holes at regular and measured distances, inserting within them silver stylets to keep them open. After a definite period he killed the animal, measured the distance between the bench marks, and found they were unaltered; there had been growth in length, but the distance between his marks on the shaft remained the same. Therefore he concluded that all growth in length must take place at the extremities of bones. At what particular part of the extremity, he makes no mention; he observed the epiphyseal lines, but left them unstudied.

Duhamel has been unfortunate in his commentators; with the exception of Flourens, who repeated and extended his experiments in 1842, all have noted his mistakes, and forgotten that he was the man—one not trained to medicine—who discovered that there was a problem of bone growth, and

SO!?

showed the world how such a problem should be solved. He made the chance observation of an English surgeon into a powerful instrument of research. He showed that bone is stained with madder only as it is being laid down. He showed that a bone grew in thickness by circumferential deposition of plate upon plate; that a long bone grew in length at its extremities; that the deepest layer of the periosteum was the maternal tissue of bone.

Our story now shifts back to London. Duhamel's researches were carried out while John Hunter was spending an untrammelled boyhood on his father's farm at Long Calderwood. But the storm which Duhamel's discoveries had raised was still in full blast when in 1748 Hunter joined his brother's school in Covent Garden at the age of twenty. The great Haller and his pupils had directed a flood of destructive criticism on Duhamel; Haller's name stood high in William Hunter's school; everything he wrote and did received the most respectful attention. If anyone was John Hunter's mentor more than another it was Haller. "How could any anatomist think," said Haller, "that bone is formed only by periosteum?" Why, one had only to look at the lower end of the thigh-bone of a child at birth to see that the theory is untrue; there one could see arteries perforate the epiphyseal cartilage, and at their growing ends see a point of ossification start into being—far removed from the periosteum. In Haller's opinion arteries were the depositors and builders of bone; he believed they could form bone anywhere within the limits of the periosteum. One has only to look at Hunter's preparations, or glance at scattered passages in his writings, to see that it was Haller, not Duhamel, who influenced him. He prepared a series of specimens to show ossific centres forming in the patella, sternum, and metacarpal bones of the calf, and in young epiphyses of human bones. These preparations show us that for him ossification was a function of arteries; ossification, he observed, always broke out at the terminal meshwork of an ingrowing leash of blood-vessels. Haller had repeated Duhamel's madder-feeding experiments, and again studied the repair of fractures, and concluded that the periosteum took no essential part in the formation of the repairing callus—the callus was formed by the broken bone; nor did the periosteum take any part in the formation and growth of bone. In Haller's opinion the periosteum was, as all surgeons then believed, merely a vascular covering to serve for the nourishment of bone. Thus, with the appearance of Haller and Duhamel we have two schools brought into existence—one which regards periosteum as osteogenetic, the true source of bone, and another which regards it as devoid of any bone-forming power whatsoever. After a century and a half of inquiry and discussion we still have these two schools.

To which of the two Hunter belonged there is no shadow of doubt. For him the normal periosteum had no bone-producing power; it was the passive vascular membrane which surrounded and nourished bone. Yet he had seen the periosteum take on an 'ossific disposition' time after time under the most varied conditions of disease and experiment. He believed with Haller—and we shall see the pains he took to verify his belief—that arteries, and only arteries, could form bone, and if periosteum should, under abnormal circumstances, become a site of bone-formation, then that was merely evidence that its arteries could assume a bone-building power.

Hunter was well aware that a fragment of living bone could be detached completely from its periosteum and yet retain its "vital principle" and survive. "In fractures," he said, "adhesion of the detached splinters also takes place . . . and this takes place not only in those which are attached to the soft parts, but even in such as are entirely loose. Therefore these pieces must retain the living principle, and probably only this, while those that remain attached have probably more. I have never examined a compound fracture without finding some of these loose pieces, which shows they must be common. Their union must be similar to that in the transplanting of teeth."* It is clear from the above statement that Hunter knew that isolated fragments of bone could be made to serve as bone grafts. The specimen which he was in the habit of showing at his lectures, to clinch the argument that a large fragment of bone might be detached from its periosteum and yet live, is illustrated in *Fig.* 684. It is a fractured femur, showing a splinter five inches in length which has been so completely detached that its position is reversed; yet it now forms a solid part of the shaft at the point of union.

FIG. 684.—Drawing of the fractured femur which Hunter was in the habit of showing to his class to demonstrate that a large fragment of bone may be detached from its periosteum and yet live and again form a union with the shaft.

We come now to trace the steps which led Hunter to recognize and explore one of the most remarkable of all the powers possessed by living tissues—the power to absorb and remove parts of their substance. The first step occurred in 1754, when he was in his twenty-sixth year and assisting in the management of his brother's anatomical school. He had then commenced his researches on the jaws and teeth, and was struck by the fact that when a tooth was extracted its socket disappeared. Thousands before him must have noted the fact, but they passed it by as self-explanatory. When he came to examine the manner in which milk teeth were shed and permanent teeth came into place, he noted that the roots of the teeth about to be cast out were eroded, and that the sockets in which they were contained were disappearing. He noted also that the last milk molar lay at the root of the ascending ramus of the mandible. But, in the adult jaw, room had been found for the additional three permanent molars between the site of the last milk molar and the ascending ramus. How could such additional

* *Collected Works*, vol. i, p. 502.

dental space be obtained unless the mandible had been remodelled during growth by a dual process of addition and abstraction. He was faced with the same problem when he came to explain how the femur of a newly-born child is transformed into that of the adult. Mere deposition of new bone at the upper epiphyseal line only adds to the upper surface of the neck of the bone. As the femur grows, its neck ought to increase rapidly in depth and breadth, unless deposition on its upper surface is accompanied by a simultaneous process of absorption along its lower surface. It thus became clear to Hunter that, from the infantile to the adult stage in the growth of a thigh-bone, the femoral neck was being continuously remodelled. Growth in bone, he concluded, entailed two distinct processes—one of deposition and one of absorption. That was Hunter's discovery. There was no need to suppose, as Duhamel had done, that the shaft of a bone actually expanded as it grew; the medullary cavity enlarged because, as new bone was deposited on the surface of the shaft, old bone was removed from its interior by absorption.

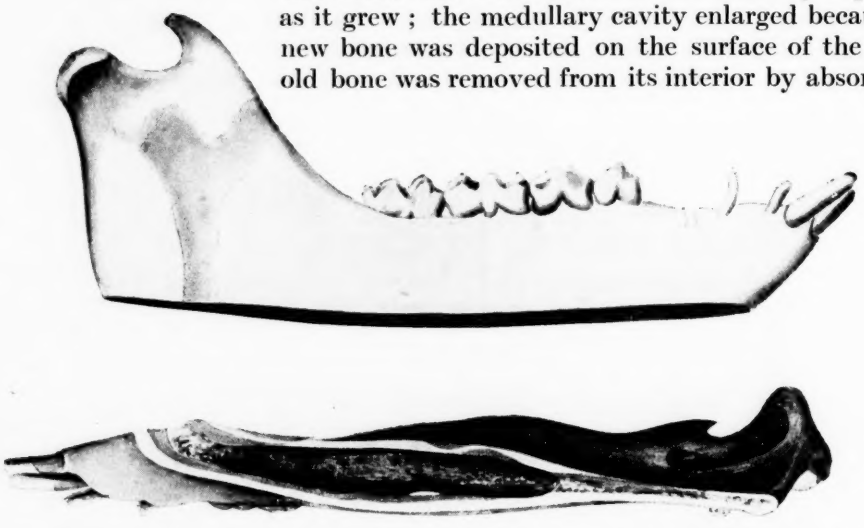

FIG. 685.—Copy of Hunter's drawing to show the manner in which growth takes place in the mandible. The drawings represent two views of the right half of the mandible of a pig, which was fed on a madder diet for a month and then for a month on normal diet. The outline of the ramus at the end of the madder period is shown by the colour. (*Copied by Mr. S. A. Sewell.*)

Soon after Hunter commenced his experimental farm at Earls Court, in 1764, he resorted to Duhamel's method to test the proof of this theory of bone growth. He fed two young pigs on a madder diet for a month; he killed one at the end of the month; the other he kept for an additional month on ordinary food before killing it. Twenty preparations from these two animals are still preserved in the R.C.S. Museum, but the colour has gone. Fortunately, there are preserved accurate 'coloured' life-size drawings of the jaw and femur of the second pig—killed a month after the madder diet had ceased (*Fig.* 685). Hunter found these two bones to answer his expectations in the most exact manner. What had been the condyle and posterior border of the mandible during the madder period were now included in the substance of the ramus—buried by the new condyle and new posterior border which had been added in the non-madder period. From the anterior border of the

ramus the madder-stained bone was almost completely removed by absorption. He found that the thigh-bone (*Fig.* 686) told the same story; what had been the upper surface of the femoral neck during the madder period was now surmounted by new bone, but on the lower aspect of the neck there was no new deposit, but a clear indication of absorption. As the result of his madder-feeding experiments, he concluded that living bone "is constantly changing its matter," and that absorption is as essential a part of bone growth as deposition.

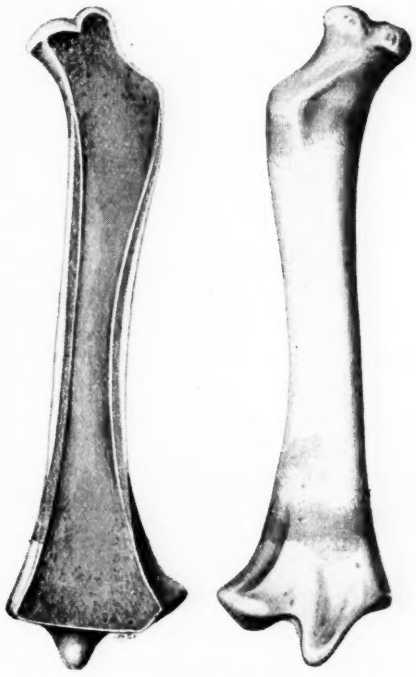

FIG. 686.—Two views of the right femur of the same animal as that from which *Fig.* 685 was taken. The position of the epiphyseal ends at the termination of the madder period is shown.

The recognition that absorption is an essential factor in the process of bone growth brought Hunter face to face with another problem during the youthful years which he spent in his brother's dissecting-room. Bone was laid down by arteries, but by which system of structures was it absorbed and carried into the circulation? At the period he was making his first investigations on the teeth—from 1754 to 1758—his brother William was proclaiming as a new discovery the absorbent function of lymphatic vessels; lymph-vessels were, he said, of the same order as lacteals; therefore they had the power of absorption. In 1758 we find John Hunter instituting experiments to ascertain if veins had the power of absorption, and apparently satisfied when he thought he had proved that they had no such power. There remained only one system of structures which could remove substances from the tissues—the absorbents. "If any solid part of the body undergoes diminution, brought on in consequence of disease, it is the absorbent system that has done it; they are the thieves!"

After having settled to his satisfaction that lymphatic vessels were the agents by which bone was absorbed and modelled, a much more difficult problem presented itself—one which shows us how deeply Hunter sought to pry into Nature's secrets. He saw that the living bone of empty tooth-sockets was removed. He was certain that lymphatic vessels were the agents by which its removal was effected. But what circumstance set the lymphatic vessels to work on the walls of the empty tooth-socket? Why should the living bone of that socket submit? In answering these questions, Hunter seems to offer us a stone rather than bread. "The remote cause of absorption of whole and living parts implies the existence of two conditions, the first of which is a consciousness, in the part to be absorbed, of the unfitness or impossibility of remaining under such circumstances, whatever they may be, and therefore they become ready for removal, and submit to it with ease.

The second is a consciousness of the absorbents of such a state in the parts. Both these concurring they have nothing to do but to fall to work."*

To any one whose imagination has not spanned the wide gulf which separates the simple hydra—Hunter's 'polypus'—from the highly organized tissues of the human body, Hunter's solution of the problem of absorption will sound like one culled from the land of dreams or of metaphysics. But to one who has spanned that gulf, as Hunter had done, and recognizes that every living particle of the human body retains something of that quality of the hydra which we name consciousness, it will be realized that Hunter's answer is a real and true one. In another paper we shall have to examine a law which is applied to explain the manner in which bones shape themselves —Wolff's law—and we shall find that unless the bone-forming and bone-absorbing cells possess just such a property as Hunter ascribed to arteries and absorbents, then such a law is without foundation; yet that law is well founded. No one has given a more vivid or a more accurate description of the manner in which a living bone casts off a dead piece than Hunter. Indeed, it was his study of necrosis and exfoliation that assisted him to realize how important an operation absorption was in the life of bones. I allude to this part of his investigations because we again find him ascribing a consciousness, not this time to the living bone, but to Nature. "Thus, while Nature is busied in getting rid of that part of the bone which is dead, she is laying on additional bone on the outside, the intention of which seems to be that of keeping up the strength of the bone, which would, without this addition, be lessened by the loss of substance. This opinion is, I think, supported by the circumstance seldom occurring in this manner in any bones but those of the lower extremity, which support the animal."† We have here formulated for us one of the chief observations on which Wolff's law is based.

We need not review Hunter's investigations of the processes involved in the healing of fractures, further than to ascertain how nearly his observations agree with those of Duhamel. Hunter regarded the vascularization of the blood-clot effused between the broken ends as the first important stage in the formation of the repairing callus. He saw that the vessels of the callus may be derived from the periosteum, from surrounding torn membranous or muscular tissue, or from the broken ends of the bone. The deposition of bone, he observed, usually commenced at the broken ends, but separate deposits might also occur in the callus. He thus differed altogether from Duhamel, who regarded the uniting callus as a product of the periosteum.

Hunter repeated Duhamel's experiments to prove that a bone could grow in length only at its extremities. He inserted two pellets in the tibia of a young pig; when the tibia was fully grown the pellets remained exactly the same distance apart. *Fig.* 687 shows the shank bones—tarso-metatarsus—of fowls on which he performed similar experiments. One of the specimens is laid open, and reveals two leaden pellets in the medullary cavity—the distance apart being exactly the same as when implanted at an early stage in the growth of the bird. The other shows two canals leading into the medullary cavity. Bristles inserted into these canals show that both are

* *Collected Works*, vol. i, p. 255. † *Ibid.* p. 574.

inclined towards the upper or proximal end of the bone where is situated the main epiphyseal line of growth. Now, when Hunter made the holes, the bone was 71 mm. long and the distance between the holes 42 mm.; when the fowl was killed, the bone was 91 mm. long and the distance between the holes 48 mm. At first sight it looks as if Hunter had proved that there had been an interstitial elongation of the shaft, for the two holes have separated 6 mm. in the course of growth. Hunter has left no interpretation; but I suspect he had fathomed the matter, and realized that he had discovered the cause of the obliquity of the nutrient canals of long bones. The periosteum is firmly fixed to the epiphyseal line at the upper end of the tarso-metatarsal shaft where all growth in length takes place. That growth causes a drag on the periosteum—a drag which decreases in degree as the distal end of the bone is

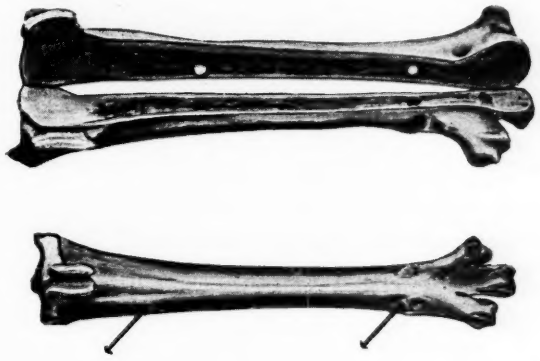

FIG. 687.— Two drawings of Hunterian specimens—both of them tarso-metatarsal bones of fowls on which Hunter experimented.

The upper bone is laid open. The pellets which were inserted in canals of the shaft at an early stage of growth are now in the medulla, but at the same distance apart.

In the lower specimen, two pins are inserted in two canals, to show that their direction is oblique. Hunter made two fine holes by a cautery in the shaft during the chick stage. He found the holes had become oblique canals, and that their external mouths had separated several millimetres in the course of growth.

approached. Hence the cauterized holes in the periosteum are dragged, during the growth of the shaft, an unequal degree towards the upper or growing end of the bone, and thus become separated to an increased extent. Sixty years after Hunter's death, Sir George Humphry explained the oblique course of nutrient canals of long bones in the exact manner shown by Hunter's experiment.

The R. C. S. Museum contains a series of specimens which represent one of Hunter's most profitable and illuminating studies of bone growth. The specimens show wonderfully injected sections and preparations of the antlers of the fallow deer at all stages of growth—in their summer velvet covering, in their late autumn condition, and in the state reached in the early spring before they are shed. He realized that Nature has never given more vivid demonstrations of bone growth, never provided such wealth of opportunities for discovering the secrets of necrosis, as in the lavish annual expenditure she makes in providing deer with antlers. No one looking at the rich carpet of arteries which clothes the surface of the rapidly growing bone would fail to conclude, as Hunter did, that arteries are the principal agents in bone formation. We shall see how far the introduction of the microscope changed our point of view sixty years after Hunter's death. Meantime we note that those two men of the eighteenth century—Duhamel and Hunter—laid the basis of our knowledge as regards the physiology of bone; and of the two, Hunter laid the firmest and deepest part of that foundation.

SHORT NOTES OF RARE OR OBSCURE CASES.

TWO CASES OF STRANGULATED RETROPERITONEAL HERNIA INTO POUCHES IN THE BROAD LIGAMENT.

By C. H. FAGGE, London.

I have failed to find other examples of this lesion, either from a search of available literature or from the experience of friends, though it is not to be expected that similar cases have not been observed. In both instances I was able to convince myself that the bowel was contained in a peritoneal fossa, and had not been forced into connective tissues through a rent in the posterior peritoneal surface of the broad ligament. In the first case the pouch was below the ovarian ligament, and I cannot find any description of any pouch in this position; in the second the pouch was above the ovary and below the tube, where, I gather, a definite fossa is recognized by gynæcologists, though not, as far as I know, described by anatomists.

Case 1.—Mrs. Y., age 61, the mother of five children, was seized with sudden abdominal pain on Dec. 9, 1916, while straining at stool immediately after breakfast. The only history of any accident was a fall downstairs in 1902. Beyond hæmatemesis in 1905, there was no history of any abdominal trouble. The pain was referred to the left iliac region, and she vomited several times; during the day she passed two normal motions. On a second visit, about 4.0 p.m., as pain continued to be acute, Dr. Stilwell decided that it was an abdominal emergency, and admitted her to the Beckenham Cottage Hospital after injecting a quarter of a grain of morphia.

I saw her at 7.0 p.m., when the pain, which had been relieved by the morphia, was beginning to return; her pulse was 108; nothing was to be made out on abdominal examination, except marked tenderness low down in the left iliac region; the tongue was clean; but her aspect was anxious, and in view of the history of agonizing pain, immediate operation was decided upon. No exact diagnosis was attempted before operation; the conditions which were considered as most likely were torsion of an ovarian cyst, strangulated obturator hernia, or mesenteric thrombosis.

When under the anæsthetic, vaginal examination detected a fullness of the left posterior fornix, and rectal examination confirmed the presence of a mass in Douglas's pouch. A left paramedian sub-umbilical incision exposed collapsed small intestine, and lower down and to the right was a coil of ileum which was distended and purple; it could not be drawn out,

and was evidently held down in the pelvis. This and another collapsed coil were traced down to the left side of the pelvis, where they were caught and held tensely as they passed through a small hole in the peritoneum; they were obviously the afferent and efferent coils of the strangulated loop, which could be seen and felt under a layer of peritoneum, filling up the left half of the pelvis. It was at first thought that this orifice was the entrance to the inter-sigmoid fossa, but to the left the peritoneum passed over the pelvic brim, and below its margin was continuous with a tense layer of peritoneum passing on to the side of the uterus. The margin of this opening was now divided with scissors, allowing the distended purple loop of ileum to be withdrawn, when it was found that this loop had passed from behind forwards into the broad ligament, and, filling up Douglas's pouch, had formed the mass which was palpable through the rectum and vagina.

The strangulated coil was covered with hot cloths while the opening in the broad ligament—just below and median to the ovarian ligament—was closed with a continuous catgut suture. The loop actually strangulated was about ten inches long, and above this about two feet or more of ileum were distended and injected. The whole was of good tone and had a shiny peritoneal surface; therefore, as it had only been strangulated some eleven hours, it was judged to be viable and returned to the abdomen, which was closed, with a large rubber drain passed down into Douglas's pouch. Subcutaneous saline had been given throughout the operation, and rectal saline was given during the following night.

The next morning there was considerable abdominal pain, with distention of the lower abdomen; there was no sickness, but much offensive gas was eructated. Water by the mouth and pituitrin were given; she had some sleep after a morphia injection; saline was given per rectum, and on Dec. 11 she had $\frac{1}{60}$ gr. of eserine, after which a good deal of fluid deeply coloured with blood was passed per rectum. Eructation now ceased, and several loose motions were passed during the next two days. Recovery was only prejudiced by a mild bronchopneumonia on the sixth day.

In February, 1917, she had another attack of severe left-sided abdominal pain, and this recurred in March; she was admitted to Guy's Hospital, where an *x*-ray examination after a bismuth meal gave no definite evidence. On March 12 the abdomen was again opened, and extensive adhesions between the scar and the lower ileum were freed; the hole in the left broad ligament was still closed. In January, 1918, Dr. Stilwell reported that the patient remained well.

Case 2.—Miss P., age 49, was seized with abdominal pain at 2.0 a.m. on Nov. 30, 1917; she vomited at intervals, and her bowels acted twice. Dr. Mowll saw her on the morning of Dec. 1, when she did not appear acutely ill; her pulse-rate and temperature were normal; she continued to vomit occasionally, and the pain was not severe. On the next day she was not so well, and fainted. On Dec. 3 she still vomited occasionally, and the pain, located to the middle of the abdomen, was severe; there was now slight rigidity and tenderness over the right rectus slightly internal to McBurney's point. Dr. Mowll diagnosed appendicitis, and admitted her to Surbiton

Cottage Hospital, where an enema was given with no result; her pulse was then 86, and her temperature slightly raised.

When I saw her, at 7.0 p.m. on Dec. 3, her pulse-rate had risen to 100; the physical signs were unaltered since the morning, and did not suggest a grave abdominal condition. The history of the attack and the location of the pain to the right iliac fossa naturally led Dr. Mowll to the diagnosis of acute appendicitis, with which I candidly agreed; the point of chief tenderness was perhaps more than usually median, but this might have been occasioned by an inflamed appendix hanging over the pelvic brim.

A free right paramedian incision exposed a healthy appendix; the small intestine was slightly distended, and there was an abnormal amount of clear fluid in the peritoneal cavity; on passing the hand into the right side of the pelvis, a coil of the lower ileum was found to be fixed to the back of the right broad ligament. Further exposure, with traction, showed a blue cyst-like body in the substance of the ligament to the back of which the loop of ileum led. After the experience of the first case, I recognized the condition present, and, defining the upper crescentic margin of the orifice, I cut it with scissors, releasing about two inches of ileum, congested but shiny, and with anæmic rings at the two ends where constriction had been caused by the margin of the ring; it had just the usual appearance of a similar coil released from a strangulated femoral hernia. I could now demonstrate that the pouch into which it had passed was above the ovary and its ligament; and, as by the division of its neck it had been converted from a saccular pouch into a shallow fossa incapable of encouraging a similar retroperitoneal hernia, I did not think its obliteration by suture necessary. The abdomen was closed without drainage.

The patient made an uninterrupted recovery, and left the hospital on the sixteenth day. She has remained well since.

REVIEWS AND NOTICES OF BOOKS.

Troubles Locomoteurs consecutifs aux Plaies de Guerre. By AUG. BROCA. Small 8vo. Pp. 155. 1918. Paris: Masson et Cie. 4 fr. net.

PROFESSOR BROCA deals with his subject from the pathological aspect, basing the proper treatment of ankylosed and stiff joints upon the appreciation of the exact anatomical or pathological obstruction to movement. He also defines ankylosis as the stiffness which results after the original injury or inflammation has subsided, pointing out that too often the stiffness is treated at a stage when the treatment ought really to be directed to the cure of the inflammation. Not seldom these two points are forgotten by the enthusiastic surgeon or by his masseur: by the former because he does not think in terms of pathology; by the latter because he is ignorant and has not received adequate instruction from the surgeon. If Professor Broca's book is read sufficiently widely to correct these faults, he will have done good work.

In the main the advice and opinions expressed will be found to be in agreement with those of the best known English orthopædic surgeons. For example, the chosen positions for fixation of the various joints are similar to those adopted in this country, and the principles of the use of mobilization will find general acceptance; so also will the author's general condemnation of the wide early excisions so often done in war surgery, which leave flail joints with such a poor functional result. Perhaps, however, Broca esteems a little too lightly the results attained by operative measures such as arthroplasty and tendon transplantation, which have found considerable favour in this country. The book can certainly be recommended to all who have to deal with the late results of war wounds, and who have to solve the problem of making good the functional utility of the damaged limb.

The Collected Papers of the Mayo Clinic. Vol. VIII, 1916. Edited by MRS. MELLISH. Large 8vo. Pp. 1014, with 411 illustrations. 1917. London and Philadelphia: W. B. Saunders Co. $6.50 net.

AN endeavour to discover in this volume any new line of thought or any departure from the beaten track which might distinguish it from its predecessors, led to a momentary joy upon the discovery of a short article by Beckman on spinal-cord tumours, of which he reports eighteen cases. This sensation was speedily destroyed by the discovery of an obituary notice of its author, which pays just tribute to his sound decision in difficulty and to his capacity for work. Several years ago we had an opportunity of watching Dr. Beckman when in charge of the 4th Surgical Theatre at Rochester, and were much struck by the delicacy and precision of his technique in deep dissections of the neck, and also by the scientific bent of his mind. His death, the result of an acute infection acting on a delicate physique already damaged by much physical and nervous wear and tear at high speed, will be a great loss to the personnel of the Clinic.

The main value of this publication rests upon its statistical worth as a record of a vast number of cases of certain ailments, excellently observed under scientific conditions, and most ably treated; dealing with such large numbers, the common errors of statistics are correspondingly diminished; moreover, the reports emanate from men who, working together, become so experienced that the personal factor is less likely to lead to false opinions and deductions. Thus, in comparing the relative mortalities of cholecystectomy and cholecystostomy, Dr. Charles Mayo has available 2493 examples of the former and 2854 of the latter operation, performed by the staff of the Clinic within nine years.

There are again in this, as in former volumes, numerous papers upon ulceration of the stomach and duodenum, upon disease of the gall-bladder, and upon goitre, none of which show appreciable advance upon similar papers in former volumes.

Drs. William and Charles Mayo contribute two very similar papers upon the treatment of cancer of the rectum, for which 430 patients have been treated by radical operations; opinion is evidently now inclining towards the abdomino-perineal operation in suitable cases; and its division into two or three stages is advocated.

Dr. Samuel Robinson, in a long paper, deals very thoroughly with the surgery of bronchiectasis; the pathological conditions found in this disease are considered in detail, and, having reviewed the different lines of medical treatment unfavourably, the author advocates some type of radical operation; this is divided into two or three stages.

Dr. Henderson's article upon derangements of the knee-joint is largely a *résumé* of the writings of English surgeons; these injuries must be relatively rare in the States, and surgeons there obviously do not enjoy the clinical experience on which Rutherford Morison and Martin of Newcastle have founded their well-known writings; there is no reference to the type of injury which Morison designated 'bucket-handle fracture,' and the author does not seem to have appreciated the fact, which appears to us fundamental, that the disability is always due to a fracture and not to a complete displacement of one of the menisci.

We have drawn attention before, to the drawings which always adorn these volumes; those in this number are no less beautiful and no less well chosen than others which have appeared in previous years, and their reproduction results in a work of art for which both the artist and publisher deserve the reader's thanks.

Découverte des Vaisseaux Profonds par des Voies d'Accès Larges (Exposure of the Deep Vessels by Free Incisions). By J. FIOLLE and J. DELMAS. 1918. Paris: Masson & Cie. 5 fr.

M. PIERRE DUVAL writes a short preface in which the aim of the authors is outlined. The volume itself, of some 120 pages, has at first sight somewhat the appearance of a guide to methods in use in an operative surgery class; yet it is really based on personal practical experience on the French front. The authors have discovered, or at least put on paper, a fact of practical value with which any surgeon with experience at a casualty clearing station will agree—viz., that under the conditions of injury which exist, a very free incision is required for the adequate exposure and determination of extent of injury of the deep vessels. When we have given them credit for this point, there is very little else in this volume to recommend it, save the obviously practical and careful methods advocated. The median calf incision for exposure of the posterior tibial vessels and nerve—perhaps the most troublesome of any in actual casualty-clearing-station practice—is now widely used in the British Imperial clearing stations; the description of this operation is admirable, and will well repay reading by those who anticipate work of this kind. Another sound chapter is that which deals with the method of access to the large vessels at the base of the neck, though the possibility of injury to the thoracic duct has evidently not struck the authors, for no mention is made of this structure beyond the remark that it is exposed in the field of operation on the left side. There is no clear reason why no chapters are devoted to the deep femoral, or to any of the iliac vessels, unless it be that the methods in common use are regarded by the authors as adequate; this is certainly not the case with the deep femoral vessels, and the reviewer would have thought that no vessel in the body would better repay the writing of a chapter—comprising both theoretical investigation on the cadaver and practical experience on the living—on the best method of access to this vessel; for anyone who has had to deal with wounds which may have involved this vessel or its branches will agree that they set no mean problem to the surgeon.

The great defect in practical teaching and disadvantage in actual practice, which this volume cannot eliminate, concerns the fact that the surgeon in dealing with the wounds of war cannot in most cases choose his incision for himself; its line is fixed by the wounds of entry and exit, and by the track of the projectile; these must be excised, and only in exceptional cases will a fresh incision to deal with vascular complications be justifiable.

Ambulance de "l'Océan," La Panne. Fasc. 1, July, 1917. Large 8vo. Illustrated. Paris: Masson & Cie. 30 fr.

DR. DEPAGE in this, the first, volume promises to issue every six months a similar one giving an account of the work of the different departments of his field hospital founded near the end of 1914. Those who have had the opportunity of visiting both the excellent main hospital and the advanced abdominal station established opposite Dixmude in June, 1916, will agree that excellent material should exist to sustain the interest in these publications during the War, and will congratulate the editors upon their happy thought in analyzing their experience and in detailing their methods for the education of the Medical Services of the Allies. A large portion of this volume is occupied by an account of the establishment and its organization; the remainder is filled by papers, chiefly clinical, upon the cases already treated and the methods in vogue.

An abundantly illustrated article by Professor Debaisieux on the early treatment of wounds gives a full description of the problems which arise and of the factors upon which the value of primary excision and Carrel's disinfection depends; this leads naturally to a chapter by Dr. Lagasse on the secondary suture of wounds, in which excellent photographs show what can be done by rigidly adhering to the indications afforded by Carrel's bacterial count. Similarly satisfactory results are available for the inspection of all medical visitors to the Ambulance.

A third noticeable paper is by Dr. Janssen on wounds of the skull and brain; much space is devoted to the consideration of the morbid anatomy of these wounds; the principles guiding treatment and the methods adopted do not differ from those in practice in the British Medical Service.

We shall look forward with interest to the succeeding volumes, and trust that the articles dealing with the department for the manufacture of artificial limbs will do justice to the ingenuity and skill of those who have organized and who administer this branch.

Memoranda on Army General Hospital Administration. By Various Authors. Edited by P. MITCHELL, M.D. (Aberdeen), Lieut.-Colonel R.A.M.C. (T.) Demy 8vo. Pp. vi + 109, with 10 illustrations. 1917. London: Baillière, Tindall & Cox. 5s. net.

THE Army Medical Service has grown by slow degrees to its present state, and in its growth has acquired by a process of accretion many cumbrous methods and administrative faults, the result of a long peace, a small army, and few sick. Civil hospitals have laboured under similar defects, but a wholesome atmosphere of criticism, coupled with the necessity for self-preservation owing to the fact that they were unendowed, have simplified the methods and cured many of the defects. One of the great and lasting advantages which the Army Medical Service will gain from the present war is the dilution of the regular service with civilian practitioners, many of them with great administrative experience. These men, being bred up in a freer atmosphere and approaching their work untrammelled by service conditions, see how the various problems can be solved without necessarily taking the line of least resistance. From the advances that have already been made, it seems clear that the solutions offered are carefully considered by the military authorities, and in many cases adopted. This is the right spirit in which to work, and by so doing our Army Medical Service will gain an even higher position than it now holds in the estimation of the public.

Colonel Mitchell, the officer commanding No. 48 General Hospital in Salonica, writes the articles in this volume on "The Officers," "The Co-ordination of the Civil and Military Medical Demands during a prolonged War," "The Nursing Service," and "Kitchens and Cooks." He commits the consideration of "The Medical Service" to Major A. W. Falconer; "The Surgical Service" to Major G. H. Colt; "Camp Sanitation" to Captain Robert Richards, and "The Quartermaster's Duties" to Lieutenant S. Taylor. The articles written by Colonel Mitchell and Major Colt are especially worthy of consideration. Some of the suggestions are certain to meet with whole-hearted approval. Examples are the abolition of the present extraordinarily cumbrous system of diet sheets, which would not be tolerated for a moment in any civil hospital, and of the employment of highly skilled and trained medical

officers upon work which could be equally well done by a clerk. Other suggestions are more difficult to carry out in actual practice, as that of grading and utilizing medical officers according to their aptitudes; whilst others again are inadvisable, as in alternating officers for short periods at home and abroad. Major Colt devotes a portion of his article to the production of a 'wall card' designed to act as a diet sheet, medical case-sheet, temperature chart, and transfer certificate. A step in this direction has already been taken by the War Office, but Major Colt's card is more elaborated than that at present in use.

Genito-Urinary Surgery and Venereal Diseases (White and Martin). By EDWARD MARTIN, A.M., M.D., B. A. THOMAS, A.M., M.D., and S. W. MOORHEAD, M.D. Pp. 929, with 422 engravings and 21 coloured plates. Tenth edition. Large 8vo. 1917. Philadelphia and London: J. B. Lippincott & Co. 30s. net.

A NEW edition of this volume is particularly welcome at the present time, when the establishment of venereal clinics throughout the country is really materializing, and when it becomes more necessary than ever for the practitioner to add further to his knowledge of the subject.

All genito-urinary diseases—medical and surgical, affecting male and female, young and old—are gone into fully. The general scheme is excellent, and not only is treatment given in detail, but pathology takes its deservedly prominent place. A notable feature is the sanity of the views expressed throughout the book; it is essentially practical, while the simple language in which it is written is admirable. New ground covered, or old material revised, includes vaccine and serum therapy; tests for renal function; destruction of vesical new growths by high-frequency dessication; the laboratory diagnosis of syphilis and control of treatment; and the treatment of the enlarged prostate. The coloured plates illustrating syphilitic skin lesions, and the treatment of the various venereal diseases, are particularly good, while a large coloured plate is most helpful to the better understanding of the Wassermann technique.

We cannot agree that the best instrument for the diagnosis of a stricture is a bougie or urethrometer; these may be useful in some cases, but a diagnosis of urethral stricture should always be made with the urethroscope. Nor can we agree with the method advocated for the opening of a prostatic abscess, for when so treated an incurable fistula frequently persists; this risk can only be avoided by draining the abscess into the prostatic urethra, approach being obtained by opening the urethra just in front of the prostate gland.

For the next edition we suggest the incorporation of diagrams which will illustrate the anatomy and embryology of each area as it is dealt with; these would be most useful to a busy practitioner, who probably has only short periods of time at his disposal for reading. A few clerical errors are to be noticed in the text, doubtless due to war conditions. The illustrations and plates are profuse, and a good detailed index adds considerably to the value of the volume. This readable book is a leading work upon its subject, and can be thoroughly recommended.

Le Péritoine en Chirurgie de Guerre. Etude Clinique. By M. STASSEN and J. VONCKEN. 8vo. Pp. 168, illustrated. 1917. Paris: Baillière et Fils.

THIS book is a record of clinical and pathological observations founded on experience of abdominal wounds at an advanced operating centre behind the Belgian lines. Though it contains little that is new to those who have been called upon to do similar work with our own armies, yet it is a most admirable exposition of the present state of abdominal surgery under modern conditions of warfare. To secure the best results in these cases, transport of patients must be reduced to a minimum by having the stations within a short distance (two or three kilometres) of the line, and operations must necessarily be carried out in surroundings which are somewhat crude, and under conditions which make scientific observation difficult. Nevertheless, the book is a striking record of surgical success in a field which at the commencement of the war was thought to be barren.

Difficulties of diagnosis dominate the whole picture, and necessitate the provision

of these special units where every case which has a possible penetrating wound of the abdomen may be sent for observation by a specially skilled staff. Formal diagnosis is rarely possible, for by the time that the classic symptoms of perforation present themselves the most favourable moment for operation has passed.

Penetrating wounds of the upper third of the thigh, the buttocks, perineum, and lower thorax are all suspicious.

The 'false abdomen,' penetrating wounds with hæmorrhage only, and penetrating wounds which flood the abdomen with intestinal contents, may all present the same initial symptoms. Cases of extraperitoneal injury only—the 'false abdomen'—especially if accompanied by severe hæmorrhage, as from the kidney or by damage to the osseous pelvis, may give rise to any or all of the symptoms of peritoneal shock; at the same time, multiple lacerations of the intestinal wall may cause so little local or general disturbance that a false sense of security is engendered. Though no one symptom can be considered diagnostic of perforation, it may be said that a general board-like hardness of the abdomen, persistence of shock in spite of measures taken to combat it, a rising pulse, and bad facies, present a syndrome which when present is rarely at fault as pointing to perforation; whilst consideration of the probable path of the missile, radiography, and the reaction of the patient under conditions of warmth and rest, are helpful—but occasionally misleading—aids to diagnosis.

These difficulties in diagnosis have led the authors to the same conclusion as that formed by most surgeons, that is, to explore when in doubt. Exploratory laparotomy may be performed through a very small incision, when the presence of blood, gas, or other foreign matter should lead to an enlargement of the wound and a thorough overhaul of the whole peritoneal cavity. On the other hand, in some cases they prefer a dissection out of the track of the missile, layer by layer, till it is clear by actual demonstration that it has or has not penetrated the peritoneum. On the whole this latter course does not appeal to us, for it does not absolutely exclude intraperitoneal visceral injury by impact without penetration: we prefer this *débridement* to be done as a secondary operation, after laparotomy has demonstrated unmistakably the presence or not of intraperitoneal injury. This criticism, however, is on a minor point of operative technique in a book devoted almost entirely to clinical and pathological observations, for which we have nothing but praise.

The Surgical Operations on President Cleveland in 1893. By W. W. KEEN, M.D., LL.D. Pp. 52. 12mo. Philadelphia: George W. Jacobs & Co.

THIS is an interesting excursion along a bypath of medical history, by a veteran surgeon who took a leading part in the adventure. Professor Keen—who, doubtless in consequence of the war, is now described as a Major in the Medical Reserve Corps, United States Army—tells for the first time the story of the operations performed upon President Cleveland for malignant disease of the superior maxilla in July, 1893. The United States was passing through so grave a crisis at the time that it was described afterwards as "the most deeply-seated financial storm in the history of the country." It was thought, and, as the event proved, thought correctly, that "Mr. Cleveland is about all that stands between this country and absolute disaster, and his death would be a great calamity." Had his influence been removed, even temporarily, the wrecking party would have been in the majority and the panic would have become uncontrollable. It was of the utmost importance, therefore, that the illness of the President and the performance of a serious surgical operation should be kept a profound secret. The ubiquity of the press and the restless energy of the reporters made concealment difficult, but Professor Keen describes the steps by which the operation was accomplished on board the yacht *Oneida* whilst she steamed at half speed up the East River. Dr. Bryant, of New York, was the actual operator, Professor Keen assisted, and Dr. Hasbrouck, a dentist, gave the anæsthetic. The operation was performed on July 1; on July 5 the President walked ashore; and on Aug. 5 he opened Congress, without anyone suspecting what had occurred. He survived the operation until 1908.

The story is admirably told, and gives a lively picture of the means taken to outwit the press. The book is daintily produced, and is a credit to the publishers.

EDITORIAL NOTICE.

The shortage and increased price of paper make it necessary to effect some economy in the issue of the next volume. So far as can now be seen, this will not involve raising the price or curtailing the matter ; but will be brought about by using a slightly smaller type and setting it closer, and by giving smaller margins. In this way each number, whilst consisting of about 150 pages as compared with 200 in former volumes, will represent the same amount of material, both letterpress and illustrations.

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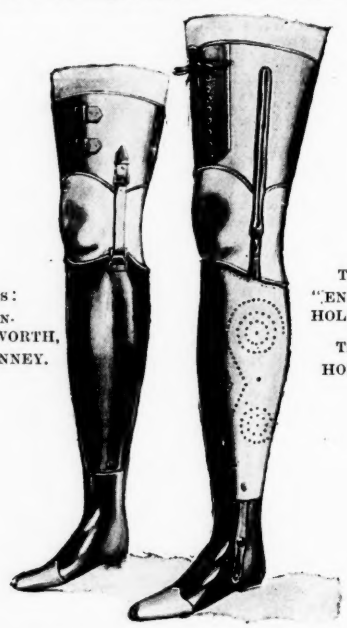

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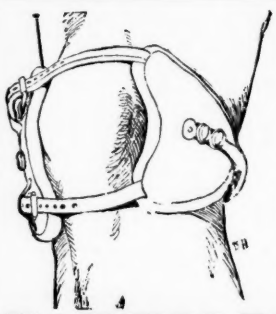

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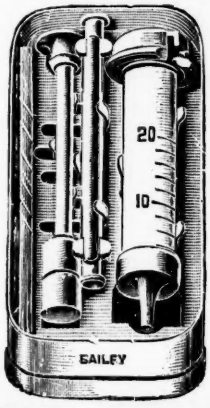

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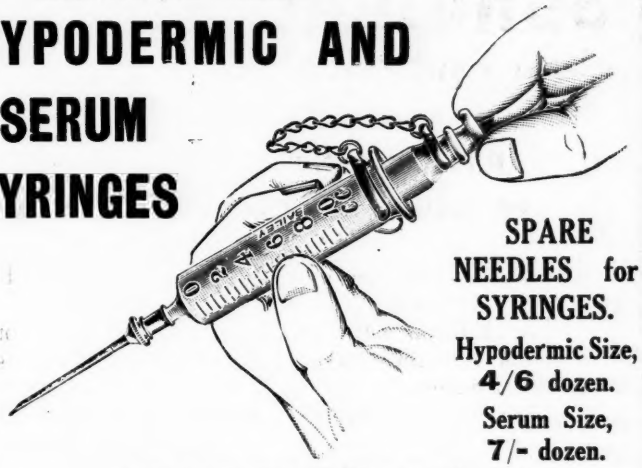

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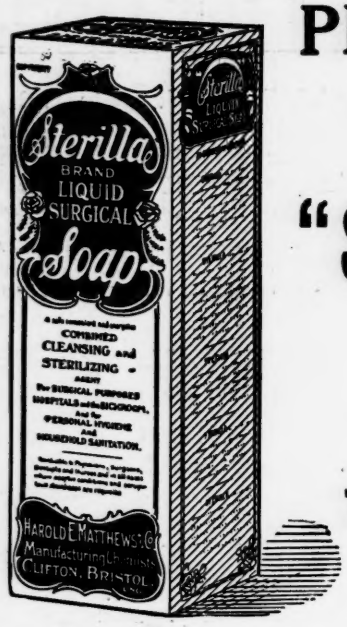

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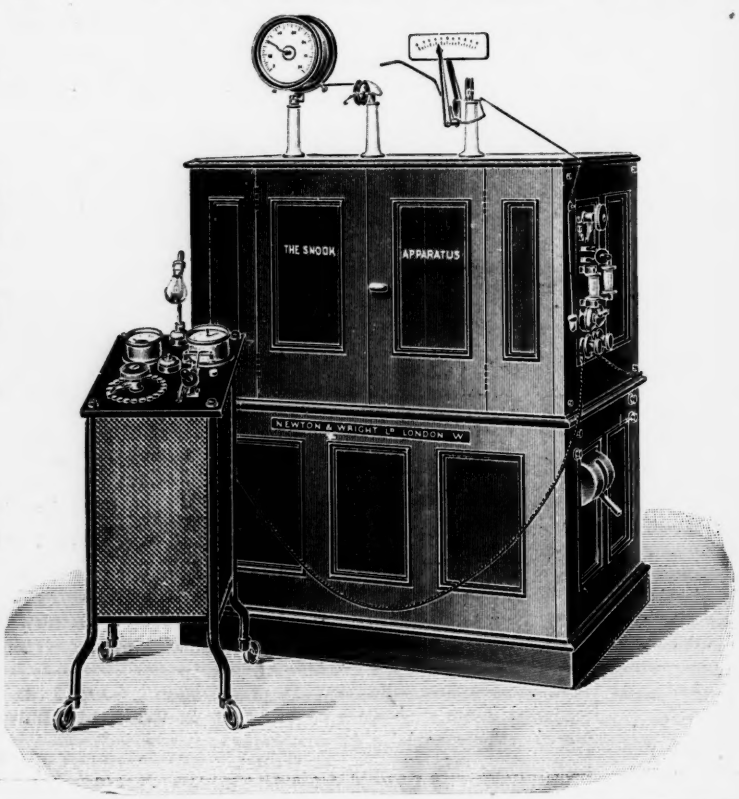

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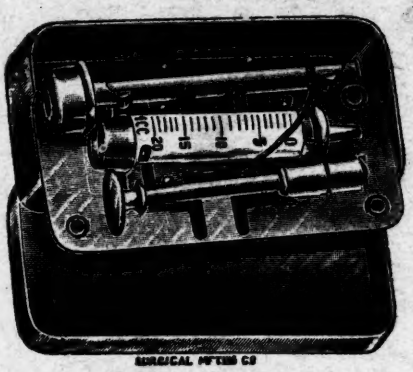

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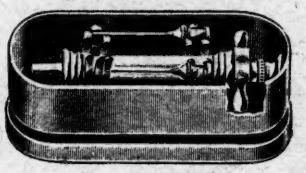

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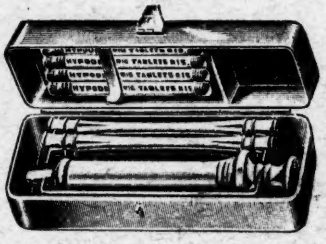

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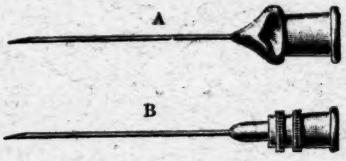

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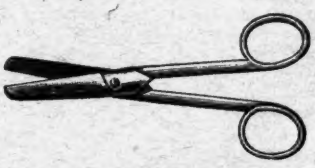

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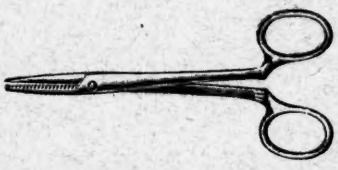

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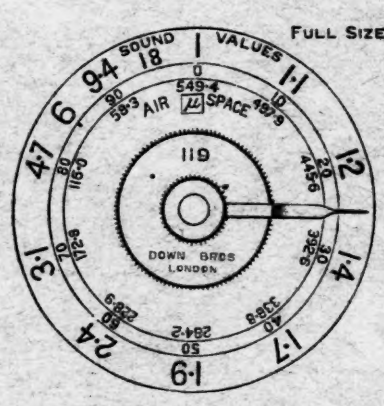

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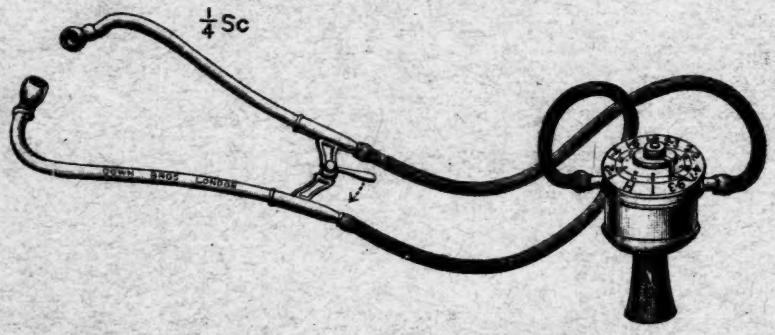

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